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Kamakura Corporation
Modeling and Analyzing
Market Risk Capital Requirements
Under the
Basel III Internal Models Approach
With
Kamakura Risk Manager

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MODELING AND ANALYZING MARKET RISK CAPITAL REQUIREMENTS UNDER THE BASEL III INTERNAL MODELS APPROACH WITH KAMAKURA RISK MANAGER

Historical Background and Executive Summary

Credit Risk Capital Requirements and the Growth of Complexity

A dominant theme in the history of the Basel Capital Accord has been increasing complexity of the analysis required to meet the most sophisticated approaches allowed for calculating a bank's minimum regulatory capital. A very brief review of this history brings this trend into clear focus.

The original accord (now referred to as Basel I) became effective on January 1, 1988. It dealt explicitly only with credit risk. (The parameters were intended to be sufficiently conservative to require capital coverage for other risks not explicitly reflected in the calculation.) Having been rushed into its final form in less than two years, the structure of the calculation was extremely simple. There were no alternative approaches, so the one-size-fits-all framework had to be simple enough to be applied by banks of all sizes without an unrealistic amount of sophisticated expertise. The following table summarizes this original framework:

Claim	Assessment		
	OECD	Non-OECD	All
Sovereigns	0%	100%	
Commercial Banks	20%	100%	
Multi-National			20%
Secured Residential			50%
Corporates			100%

The most significant characteristic of this table is the breadth of the asset categories and the small number of different risk weights (only seven in all). For most small to medium-sized banks in OECD¹ countries, as few as four distinct risk weights were relevant, namely:

- OECD Sovereigns
- OECD Banks
- Secured Residential Mortgages
- Corporates

Assets only needed to be divided into these four categories. Once these totals were established, the capital calculation could be done by hand on the back of an envelope.

In Basel II life became far more complicated, even for banks that chose to apply the simplest standardized approach. The following table illustrates this point.

Claim		Assessment					
		AAA	A+ to A-	BBB+	BB+ to B-	Below B-	Unrated
Sovereigns		0%	20%	50%	100%	150%	100%
Banks	Option	20%	50%	100%	100%	150%	100%
	Option	20%	50%	50%	100%	150%	50%
Corporates		20%	50%	100%	150%	100%	
		AAA	A+ to A-	BBB+	Below BB-	Unrated	

The OECD/non-OECD distinction has been eliminated but all exposures now need to be combined into common categories by credit rating. To perform this stratification requires extracting data at the detailed level from loan or risk systems. Simply extracting broad classes of assets (sovereigns versus banks versus corporates) which were commonly available from financial statements or existing regulatory reports was no longer sufficient.

Market Risk Capital Requirement

In the early 1990s it became clear that market risk in the mark-to-market book was becoming an increasingly important risk for many large money-center banks. A supplemental capital charge to reflect this growing form of risk was initially proposed in 1993. It is illustrative of the growing complexity of the Accord that finalizing this change took over twice as long as the process to develop and implement the original Basel I framework. The market risk amendment did not take effect until January 1, 1998.

¹ OECD stands for the Organization for Economic Cooperation and Development. The distinction in the original Basel Accord between exposures to entities in OECD versus non-OECD countries was the source of some widely noted anomalies. Most particularly, exposures to entities in Turkey, an OECD member, attracted less regulatory capital than similar exposures to entities in Singapore, even though Singapore was widely recognized as a better sovereign risk.

The most significant aspect of the market risk amendment was that it permitted the use of internal Value-at-Risk models to estimate the capital charge, subject to specific structural characteristics and a regulatory approval of a bank's analytical and operational methods. It is important to remember that market risk in the late 1990s was driven primarily by changes in broad structural variables such as interest rates, FX rates and commodity prices. Even then, however, it was recognized that a trading portfolio of fixed income instruments issued by private institutions embodied risks above and beyond changes in the level of general interest rates. This additional risk stemmed from the potential for changes in the credit quality of the obligors to specific securities. For convenience this could be broken down into changes in the credit spreads for a given category of credit quality plus potential changes in the credit standing of individual issuers. To capture this additional risk structurally would require explicit modeling of the credit spreads for all underlying issuers in conjunction with modeling changes in the general level of interest rates. In the absence of such detailed modeling of credit risk, banks were allowed to reflect this 'specific risk' by applying a simplified formula. Given the level of the simplified supplemental charge and the cost and complexity of implementing full specific risk modeling, virtually all banks chose to simulate only the basic interest rate environment and use the simplified formula for specific risk.

Migration of Credit Risk into the Trading Book

One of the major trends of the early 21st century was the dramatic growth of credit default swaps and increasingly complex securitized debt obligations. One consequence of this was that significant amounts of credit risk migrated from the banking books into the trading books of major banks. Increasingly regulators felt that the market risk capital rules assigned inadequate capital to reflect this increase of credit risk in the trading book. Discussions were initiated to revise these rules even before the financial crisis of began in 2007 and accelerated in 2008. The severity of the crisis and the public cost of bailing out many large banking institutions clearly toughened the determination of regulators impose a significant increase in required capital. Furthermore, such increases were focused on the issue of credit risk that was deemed to be at the heart of the banking crisis. Basel III represents the culmination of these regulatory efforts.

Basel III Supplemental Market Risk Capital Requirements

The heart of Basel III is the continuation of the existing Value-at-Risk-based capital requirement plus the imposition of four supplemental capital requirements for market risk. These are:

1. The Existing Value-at-Risk-based Capital Requirement
2. A Stressed Long-Term Capital Requirement
3. A Long-Term Incremental Risk Charge
4. A Comprehensive Risk Capital Requirement
5. A Specific Risk Charge

1. The Basic Value-at-Risk-based Market Risk Capital Charge

The above supplemental capital requirements are in addition to the existing Value-at-Risk (VaR)-based capital charge. The existing charge is based on the 99% one-tail confidence interval of potential loss

from imposing the instantaneous equivalent of a 10-day move in underlying market rates or prices. More specifically, it is the maximum of the latest daily VaR metric for the previous business day and the average of these metrics over the previous 60 business days. This value is multiplied by a bank specific regulatory factor, with a minimum value of 3.0, to arrive at the resulting capital charge.

2. A Stressed Long-Term Capital Requirement

The Stressed Long-Term Capital Requirement is structurally identical to the Basic VaR-based charge except that the underlying factor model must be calibrated to historical data from a continuous 12-month period of significant financial stress relevant to the bank's portfolio.

3. A Long-Term Incremental Risk Charge

The Long-Term Incremental Risk Charge (LTIRC) *explicitly addresses the need to reflect default and migration risk over a longer time horizon than the 10-day holding period implicit in charges 1 and 2.* Under Basel III, the LTIRC represents an estimate of the *default and migration risk* of unsecured credit products over a one-year capital horizon at a 99.9% confidence level. The calculation is to take into account the liquidity horizon (the time to liquidate or hedge a given exposure) applicable to individual positions assuming maintenance of a constant level of risk over the one-year capital horizon. The liquidity horizon is to be that which would prevail in stressed market conditions and cannot be less than the smaller of three months or the contractual maturity of the position.

In essence, calculating the LTIRC is equivalent to modeling the impact of changes in issuer specific credit spreads over each liquidity horizon and then rebalancing the portfolio to restore the original level of risk exposure.

4. A Comprehensive Risk Capital Requirement

The Comprehensive Risk Capital Requirement represents an estimate of *all price risks* of the bank's portfolio of *correlation trading positions over a one-year time horizon at the 99.9% confidence level*, again assuming maintenance of a constant level of risk over the one-year capital horizon. Correlation positions include:

- A securitization position for which all or substantially all of the value of each of the underlying exposures is based on the credit quality of a single actively traded company, or
- A non-securitization position that hedges a securitization position described above.

Calculation of the capital requirement of correlation positions *requires detailed analysis of the default-adjusted performance of each underlying exposure*, with special attention to the degree of co-variation in such performance.

5. A Specific Risk Charge

Specific risk is the risk of losses on market risk exposures caused by factors other than broad market movements, including event risk and idiosyncratic risk. If a bank applies the Internal Modeling Approach



(IMA) to derivation of its Long-Term Incremental Risk Charge (item 3 above), default risk can be excluded from its specific risk calculation. Other types of event risk may give rise to a capital charge if they are material sources of potential loss.

Modeling Implications of the Basel III Market Risk Requirements

From the above description, it is clear that calculation of supplemental risk charges 3 and 4 require detailed analysis of individual credit risky entities to be embedded in the simulation. This includes both general movements in credit spreads as well as default and migration events for individual obligors. Both the volatility and the co-variability of individual firms' credit quality are essential to simulating these risks properly. Empirically grounded calibration of such simulation models requires a richer source of data than can be provided by the periodically reviewed assessments of traditional credit rating agencies.

Kamakura's daily assessment of default probabilities, combined with our tools for extending the analysis to non-public firms based on relevant structural details of each target company, provide an ideal foundation to meet the daunting new market risk capital calculations demanded by Basel III.

Basel III Market Risk Capital Requirements

The original Basel II guidelines in the Basel Committee document *International Convergence of Capital Measurement and Capital Standards: A Revised Framework* June 2006 established capital adequacy requirements for the interest rate and other market risks of financial instruments held in a bank's trading book. Under Basel II, the interest rate and other market risk capital requirements for the trading book are calculated under either the Standardized Measurement Method (SMM) or the Internal Models Approach (IMA). Under the IMA, the capital requirement is defined in a probabilistic framework involving changes in the aggregate economic value of financial instruments in a bank's portfolio over an analysis horizon period. In particular, the capital requirement is a function of the Value-at-Risk (VaR) metrics for the portfolio calculated daily over the 60 preceding business days using a 99% one tail confidence interval based upon an instantaneous shock equivalent to a 10-day movement in underlying market rates or prices. To determine the capital requirement, the higher of the value of the daily VaR metric for the preceding business day and the average of the daily VaR metric values over the preceding 60 business day period is calculated, and this result is multiplied by a factor specified by the bank's regulator that has a minimum value of 3. This results in a market-risk-equivalent asset amount equal to the market risk capital requirement times 12.5, which is required for calculation of the bank's capital adequacy ratio.

The market risk capital requirements guidelines under the IMA discussed in *International Convergence of Capital Measurement and Capital Standards: A Revised Framework* June 2006 were updated in two Basel Committee documents: *Revisions to the Basel II Market Risk Framework* July 2009 and *Guidelines for Computing Capital for Incremental Risk in the Trading Book* July 2009. These updated guidelines impose additional requirements on the calculation of the market risk capital requirement: a Stressed, Long-Term Capital Requirement, a Long-Term Incremental Risk Charge, a Specific Risk Charge, and a Comprehensive Risk Capital Requirement. The sum of the original capital requirement plus these additional requirements is considered the new market risk capital requirement under these guidelines. Collectively, the updated guidelines are considered as part of the Basel III capital adequacy guidelines.

Stressed, Long-Term Capital Requirement

Under the Stressed, Long-Term Capital Requirement, a Stressed VaR metric is calculated at the 99% one-tail confidence interval over a 10-day holding period on a daily basis as is the case with the original VaR requirement above, but the changes in the underlying risk factor vector must be simulated using model inputs calibrated to historical data from a continuous 12-month period of significant financial stress relevant to the bank's portfolio. Similar to the original capital requirement, the Stressed, Long-Term Capital Requirement is the higher of (i) its previous day's Stressed VaR and (ii) an average of the daily Stressed VaR measures on each of the preceding sixty business days, multiplied by a multiplication factor (3 or higher).

Long-Term Incremental Risk Charge

The new Long-Term Incremental Risk Charge (LTIRC) requirement discussed in detail in *Guidelines for Computing Capital for Incremental Risk in the Trading Book* addresses the need to measure default and migration risks over a longer time horizon than the 10-day holding period applicable to the VaR and

Stressed VaR calculations. Under the new guidelines, the LTIRC represents an estimate of the default and migration risks of unsecured credit products over a one-year capital horizon at a 99.9% confidence level, taking into account the liquidity horizons of individual positions or sets of positions, assuming a constant level of risk exposure over the capital horizon. The constant level of risk exposure is equivalent to rolling over that the bank's trading positions in a manner that maintains the original risk exposure level. The liquidity horizon of a position or a set of positions is the time required for the bank to reduce its exposure to, or hedge all of its material risks of, the positions in a stressed market, which may not be less than the lower of three months or the contractual maturity of the position.

Analysis of default risk for the LTIRC requires estimation of the distribution of potential credit losses on financial instruments that become defaulted over the one-year capital horizon. The amount of credit losses depends upon the probabilities of individual obligors defaulting during the capital horizon, the fractional loss severity on financial instruments associated with a defaulting obligor when a default occurs, and the exposure amount or EAD of each defaulted instrument. These default probabilities, fractional loss severities, and EADs are assumed to depend upon a collection of underlying risk factors and yield curves, which implies that default-related credit losses vary over time during the capital horizon.

Analysis of migration risk for the LTIRC requires estimation of the distribution of potential credit losses on financial instruments arising from changes in credit quality over the one-year horizon. The distribution of potential credit losses on financial instruments arising from changes in credit quality is equivalent to the distribution of differential value changes for financial instruments in the bank's portfolio over the one-year capital horizon arising from changes in the credit quality of the obligors of the instruments under the full range of risk factor vector and yield curve sample paths. The portion of the value of a financial instrument that is attributable to credit risk (the credit discount) is the difference between the default-free economic value of the instrument and the credit-adjusted economic value of the instrument. Thus the differential value change for a financial instrument that arises from changes in obligor credit quality over the one-year capital horizon is the change in the credit discount over the one-year capital horizon. Estimating the distribution of potential credit losses on financial instruments arising from changes in credit quality over the one-year horizon is equivalent to estimating changes in the credit discount over the horizon. These changes depend upon the default-free and credit-adjusted economic values of financial instruments at the beginning date of the horizon and at the ending date of the horizon.

Comprehensive Risk Capital Requirement

The Basel III market risk capital requirements also include a Comprehensive Risk Capital Requirement. The Comprehensive Risk Capital Requirement covers comprehensive risk, which represents an estimate of all price risks of the bank's portfolio of correlation trading positions over a one-year capital horizon at a 99.9% confidence level, assuming a constant level of risk exposure over the capital horizon. A correlation trading position is: (i) a securitization position for which all or substantially all of the value of the underlying exposures is based on the credit quality of a single company for which a two-way market exists, or on commonly traded indices based on such exposures for which a two-way market exists, or (ii) a position that is not a securitization position that hedges a position described in (i). Resecuritization positions, derivatives of a securitization position that do not provide a pro rata share in the proceeds of a securitization tranche, and securitization positions for which the underlying assets or reference

exposures are retail exposures, residential mortgage exposures, or commercial mortgage exposures are not correlation trading positions.

Analysis of comprehensive risk for the Comprehensive Risk Capital Requirement requires estimation of the distribution of potential economic value losses on securitization positions arising from changes in risk factors, yield curves, credit spreads, recovery rates, and other risk sources on the underlying exposures or the securitization deal structure over the one-year horizon. Since the performance of a securitization position is substantially dependent upon the performance of the underlying exposures and the correlations among the exposures, a detailed analysis of the default-adjusted performance of each underlying exposure is essential to analyzing the comprehensive risk of each securitization position.

Specific Risk Charge

Specific risk is the risk of losses on market risk exposures resulting from factors other than broad market movements, including event risk and idiosyncratic risk. Assuming the bank applies the IMA LTIRC requirement to its portfolio, default risk and migration risk are excluded from specific risk, but other types of event risk may impose a capital requirement if they are material sources of risk to the bank's portfolio.

Modeling Market Risk Portfolios

Under the Basel III market risk measurement framework, market risk is defined as the risk of losses in on and off-balance-sheet positions arising from movements in market prices. The risks subject to this requirement are the risks pertaining to interest rate related instruments and equity securities in the trading book and foreign exchange risk and commodities risk throughout the bank on a worldwide net consolidated basis irrespective of where the instruments are booked. The trading book consists of positions in financial instruments and commodities held either with trading intent or in order to hedge other elements of the trading book. Positions held with trading intent are those held intentionally for short-term resale and/or with the intent of benefiting from actual or expected short-term price movements or to lock in arbitrage profits, and may include for example proprietary positions, positions arising from client servicing (e.g. matched principal broking) and market making.

Securitization positions are covered by the Basel III market risk measurement framework. Securitization positions include securitization tranche instruments created by a securitization transaction in which: (i) all or a portion of the credit risk of one or more underlying exposures is transferred to one or more third parties; (ii) the credit risk associated with the underlying exposures has been separated into at least two tranches that reflect different levels of seniority; (iii) performance of the securitization exposures depends upon the performance of the underlying exposures; (iv) all or substantially all of the underlying exposures are financial exposures (such as loans, commitments, credit derivatives, guarantees, receivables, asset-backed securities, mortgage-backed securities, other debt securities, or equity securities); and (v) for non-synthetic securitizations, the underlying exposures are not owned by an operating company. Securitization positions also include market risk exposures that reference underlying securitization tranche instruments.

The market risk capital requirements for securitization positions that are correlation trading positions are addressed by the IMA. A correlation trading position is: (i) a securitization position for which all or substantially all of the value of the underlying exposures is based on the credit quality of a single company for which a two-way market exists, or on commonly traded indices based on such exposures for which a two-way market exists on the indices, or (ii) a position that is not a securitization position that hedges a securitization position described in (i). Correlation trading positions may include CDO index tranches, customized CDO tranches, and nth-to-default credit derivatives, and hedges of these positions may include standardized CDS index and single-name CDS positions. The market risk capital requirements for securitization positions that are not correlation trading positions are addressed under the SMM, so these securitization positions are not modeled and analyzed under the IMA.

Since VaR and LTIRC amounts are calculated in the bank's domestic currency under the Basel III IMA guidelines, any net position denominated in a foreign currency introduces foreign exchange risk. Thus all foreign currency denominated positions held in either the trading or the banking books are subject to the IMA market risk capital requirement.

A financial instrument is any contract that gives rise to both a financial asset of one entity and a financial liability or equity instrument of another entity. Financial instruments include both primary financial instruments, i.e. cash instruments, and derivative financial instruments. A financial asset is any asset that is cash, the right to receive cash or another financial asset; or the contractual right to exchange financial assets on potentially favorable terms, or an equity instrument. A financial liability is the contractual obligation to deliver cash or another financial asset or to exchange financial liabilities under conditions that are potentially unfavorable.

Under the IMA, the consolidated collection of trading book, foreign exchange, and commodity market risk exposures is modeled as a portfolio of financial instruments where each instrument represents a market risk exposure to one or more sources of market risk. The IMA requires that each financial instrument describing a market risk exposure be modeled in sufficient detail so that its current and future economic value, future cash flows, and future financial accounting income and/or expense can be estimated reasonably accurately using pricing, cash flow, and earnings models appropriate to the instrument.

The KRM solution provides the functionality required to model portfolios of financial instruments representing market risk exposures as well as the functionality required to model individual financial instruments with the detail required for current and future pricing, cash flow simulation, and financial accounting income and expense simulation. These features of the KRM solution are described in greater detail below.

Portfolio Modeling and Subportfolio Selection

The KRM solution models portfolios of market risk exposures as collections of financial instruments. Multiple portfolios can be defined and assigned a name. The models for the financial instruments in a portfolio are typically instantiated by importing attribute values for each instrument from one or more sources external to KRM. In practice, this requires that the values obtained from each source be

validated, transformed, mapped to the KRM Data Model or that default values be substituted for some attributes. A data integration (ETL) process is set up in the KRM Data Integrator to perform these actions.

The KRM solution also allows attributes of the financial instruments representing market risk exposures in a portfolio to be specified or modified interactively through use of a graphical user interface (GUI). This permits addition of small volumes of financial instruments to a portfolio to support prospective analysis of the effects of including these instruments in the portfolio.

The portfolio modeling functionality in the KRM solution supports definition of arbitrary subportfolios of a given portfolio and application of the subportfolio definition when performing various analytical processing tasks. Subportfolio definitions are specified by subportfolio selection rules that describe the criteria for a financial instrument to be included in a subportfolio. The selection rules treat the model attributes for financial instruments and other modeling elements as elements of data relations for the models within a relational database and describe the selection criteria as relational data (SQL) queries. The selection rules and criteria are interactively specified by the user through a graphical user interface (GUI).

The ability to select an arbitrary subportfolio of market risk exposures provides each client with the means to customize the display and analysis of the exposures in a portfolio. For example, the market risk exposures originated by a particular organizational unit or of a particular financial instrument type can be selected for viewing and analysis. Analyses that are only relevant to specific instrument types or geographical areas can also be applied to the specified exposures using this subportfolio selection capability.

Market Risk Exposure Modeling

The KRM solution can model the entire range of financial instruments representing market risk exposures held in typical bank portfolios that are subject to the Basel III market risk capital requirement under the IMA. Each financial instrument is modeled individually so that the specific characteristics of that instrument can be considered in portfolio analysis. Each instrument can be modeled as an asset (or long position) or liability (or short position), and the same attributes are specified for each type of instrument regardless of whether it is an asset (long) or a liability (short). There is no inherent limit on the number of financial instruments that can be modeled in the KRM solution. The following table provides a summary of the various types of instruments that can be modeled in KRM.

Instrument Category	Description	KRM Instrument Types
Fixed- or Floating-Rate Instrument	Bonds, loans, and other interest-bearing instruments.	Fixed- or Floating-Rate Instrument
Equity Security Instrument	Equity securities.	Equity Security Instruments

Instrument Category	Description	KRM Instrument Types
Securitization Tranche Instrument	Interest-bearing instruments representing securitization tranches in securitization deals, such as CMOs, ABSs, CDOs.	Securitization Tranche (Securitized Asset) Instrument
Synthetic CDO Instrument	Interest-bearing instruments representing securitization tranches in synthetic CDO deals.	Unfunded Synthetic CDO Instrument Funded Synthetic CDO Instrument
Monetary or Commodity Holding Instrument	Non interest-bearing instruments representing currencies or commodities.	Nostro Account
Interest Rate Derivative Instrument	OTC forward rate, swap, and purchased option contracts on an underlying coupon interest rate index.	Forward Interest Rate Agreement (FRA) Interest Rate Swap Contract Interest Rate Swaption Contract Periodic Rate Cap/Floor/Collar Agreement
Foreign Exchange Rate Derivative Instrument	OTC forward, swap, and purchased option contracts on an underlying foreign exchange rate.	FX Forward Rate Agreement FX Spot Rate Option Contract FX Spot Rate Swap Contract
Commodity Derivative Instrument	OTC forward, swap, and purchased option contracts on an underlying commodity price.	Commodity Forward Price Agreement Commodity Spot Price Option Contract Commodity Spot Price Swap Contract
Fixed- and Floating-Rate Derivative Instrument	OTC forward and option contracts and principal and interest strips on an underlying bond or other fixed- or floating-rate instrument(s).	Forward Purchase Cash Delivery Contract on Fixed- or Floating-Rate Instrument Call or Put Cash Delivery Option Contract on Fixed- or Floating-Rate Instrument IO or PO Strip on Fixed- or Floating-Rate Instrument
Equity Index Derivative Instrument	OTC forward, swap, and purchased option contracts on an underlying equity index return	Equity Index Swap Contract Equity Index Swaption Contract Equity Index Option Contract

Instrument Category	Description	KRM Instrument Types
Equity Derivative Instrument	OTC forward, swap, and purchased option contracts on an underlying equity instrument.	Put or Call Cash Delivery Option Contract on Equity Instrument Equity Warrant
Single-Name Credit Default Swap	OTC single-name credit default swap contracts on an underlying reference obligation.	Single-name Credit Default Swap
Nth-to-Default Credit Default Swap	OTC Nth-to-default credit default swap contracts on a pool of underlying reference obligations.	First-to-Default Credit Default Swap
Credit Guarantee	Credit guarantee on an underlying fixed- or floating-rate instrument	Credit (Loan) Guarantee Instrument
Credit Commitment	Commitment to acquire one or more underlying financial instruments	Credit Commitment Instrument

The KRM solution models each type financial instrument using a financial instrument template for that instrument type. The financial instrument template describes various mandatory and optional attributes of each instrument type, and instantiation of the attribute values results in a model for a particular financial instrument of that type. The financial instrument attributes include identification and descriptive characteristics of the instrument, contractual terms of the instrument, and references to behavioral, rate index, and other models required to describe the behavior of the instrument. Sufficient attributes are associated with each instrument type to enable the KRM solution to simulate potential future cash flows and financial accounting income and expense of the instrument and to calculate the current and future economic value of the instrument.

The identification and descriptive attributes of each financial instrument can be used to classify or categorize the instrument according to a user-defined set of categories. This allows financial instruments in a portfolio to be grouped according to one or more categorizations, and it allows the analytical results produced by the KRM Analytical Engine to be summarized and aggregated by one or more categories.

The KRM solution provides a graphical user interface (GUI) that implements the financial instrument template for each type of financial instrument as a dialog form that enables users to specify the attributes of individual financial instruments in a portfolio. This allows users to interactively modify the composition of financial instruments in a given portfolio. An example of a dialog form for fixed- and floating-rate instruments in the KRM GUI is shown below.

Fixed and Floating Rate Instruments

Screen Edit Links Help

Transaction ID: Prepay1-May03

Portfolio: PORT_YIELDPREPAY All Use External Sensitivities

General Floating Graduated Payment Options / Fees Transfer Price Credit Group User Fields

Instrument Characteristics

Coupon Type: Fixed
Amortization Type: Amortizing
IO PO: Gross Interest and Principal

Coupon

Current Rate(%): 6.0000 Original Rate(%): 0.0000
Average Rate(%): 0.0000 Net Rate(%): 0.000000

Current Payment: Calculate
Original Payment: Calculate
Adjustment: Change Maturity
Frequency: 1 Month
Payment Date Calculation: Backward from Maturity Date
Day Count: 30E/360 (ISDA)
Pay Day: 15 Payment Lag:
Payment Timing: Payment in Arrears
First Coupon: Proportional
Other Coupons: Proportional
Service Fee (%): 0.000000

Business Day

Holiday ID: USA
Holiday Convention: Ignore Holidays

Disbursement

Disbursement Date:
of Disbursements:
Disbursement Amount:
Frequency:
Repo

Repo Flag:
Repo Start:
Repo End:
Principal

Par Balance: 19,383,662.34 Asset
Book Balance: 19,083,662.34 Liability
Average Balance: 0.00 Currency: USD
Original Balance: 19,676,446.84
Accrued Interest: 0.00

Index Linked Principal

Index For Principal:
Frequency:
Payment:
Sinking Fund

Rate:
Freq:
Sinking Day:
Amortization Amount:
Original Amount:
Payment Type:
Dates

Origination: 2002-12-15 Maturity: 2012-12-15
Trade: 1900-01-01 Termination:
Amortization Start: 2002-12-15 Amortization Maturity:
Original Maturity: 0000-00-00 Original Amort Maturity:
First Coupon: Calculate Last Period Start: Calculate
Previous Payment: Calculate Next Payment: Calculate
Settlement Dates

Date: 2003-02-10 Price: 99.40420
Delay (Days):
Repo

Securitization positions are modeled in the KRM solution as securitization tranche instruments (securitized assets or as synthetic CDOs) using a composite modeling and analysis platform. The composite platform consists of the KRM solution components together with supporting securitization analysis functions and a securitization deal database. Some securitization analysis functions provide access to the detailed information retained in the securitization deal database, including the tranche structure and contractual terms, the financial instruments in the underlying asset pool, and the cash flow waterfall. Other securitization analysis functions accept simulated market and behavioral inputs and simulate aggregate cash flows from the underlying asset pool, including defaults, recoveries, and prepayments. Additional securitization analysis functions interpret the internal representation of the deal structure and cash flow waterfall associated with each securitization deal and simulate the allocation of asset pool cash flows to each tranche in the securitization structure. The KRM Analytical Engine simulates the market and behavioral inputs to the asset pool cash flow simulation process and uses the cash flow simulation and allocation functions to calculate the projected future cash flows of a

securitization tranche instrument under the input sample paths. The composite platform can use the securitization analysis functions and a securitization deal databases offered by or Intex Solutions Inc., Markit Group, or Trepp LLC for this purpose.

The KRM solution can model positions where a specified amount of a commodity is held and commodity derivative instruments using the foreign exchange analogy, where each commodity is treated as a currency denomination and the spot commodity price is the spot FX rate between one unit of the commodity and the monetary base currency denomination. For example, natural gas delivered at the Henry Hub is priced in US dollars for units of 1 million BTUs and by the FX rate analogy would be the spot FX rate between 1 million BTUs and US dollars.

Market and Credit Risk Hedge Modeling

Under the IMA, trading assets and trading liabilities that hedge other trading assets and liabilities in the bank's trading book are considered as risk mitigants if the hedge is within the scope of the bank's hedging strategy. The trading strategy must articulate the expected holding period of, and the market risk associated with, each subportfolio of trading positions. The hedging strategy also must articulate for each subportfolio the level of market risk the bank is willing to accept and must detail the instruments, techniques, and strategies the bank will use to hedge the risk of the portfolio. The hedging strategy should be applied at the level at which trading positions are risk managed at the bank (for example, trading desk, portfolio levels).

Under the IMA, both market and credit risk hedging strategies can be used to hedge the risks of trading book risk exposures. Market risk hedges offset the market risk of one or more hedged financial instruments. The hedging instruments employed in market risk hedges include many of the types of instruments identified in the market risk exposure table shown above. For example, an OTC forward contract on an underlying bond can be used to hedge the risk of changes in the price of the bond prior to the expiration date of the forward contract. The KRM solution models these hedging instruments in the manner discussed above.

Credit risk hedges offset the credit risk of one or more hedged financial instruments. Credit risk hedging instruments cover losses on hedged financial instruments when an obligor defaults. Loss coverage is provided by liquid collateral assets (funded coverage), third-party payment (unfunded coverage), or netting of hedged and hedging positions (netted coverage). The KRM solution can model most common forms of credit risk hedging instruments, as shown in the following table.

Instrument Category	Description	KRM Instrument Types
Collateral Agreement (Funded)	Contracts providing for contingent settlement by liquidation of a collateral pool of a counterparty's obligations under a financial instrument or other contract issued by the counterparty in the event of default of the counterparty.	Collateral Agreement (CA) Instrument Long Protection
Contingent Liability (Unfunded)	Contracts providing for contingent settlement by a third party of a counterparty's obligations under a financial instrument or other contract issued by the counterparty in the event of default of the counterparty.	Single-Name Credit Default Swap (CDS) Long Protection First-to-Default Swap (CDS) Long Protection Credit Insurance (CI) Contract Long Protection Credit (Loan) Guarantee (CG) Instrument Long Protection
Bilateral Position Netting Agreement (Netted)	Contracts providing for termination and novation or offset of a collection of netting items covered by each agreement denominated in the same currency in the event of default of the counterparty to the agreement.	Bilateral Position Netting Agreement (BPNA) Instrument
Cross-Product Position Netting Agreement (Netted)	Contracts providing for termination and novation or offset of a collection of netting items covered by each agreement in the event of default of the counterparty to the agreement.	Cross-Product Position Netting Agreement (CPNA) Instrument

The KRM solution models each type credit hedging instrument using a financial instrument template for that type of instrument. The financial instrument template describes various mandatory and optional attributes of each instrument type, and instantiation of the attribute values results in a model for a particular financial instrument of that type. The financial instrument attributes include identification and descriptive characteristics of the instrument, contractual terms of the instrument, and references to behavioral, rate index, and other models required to describe the behavior of the instrument. Sufficient attributes are associated with each instrument type to enable the KRM solution to simulate potential future cash flows of the instrument and to calculate the economic value of the instrument.

KRM models the credit hedging relationship for each credit hedging instrument as part of the financial instrument template. The credit hedging relationship identifies the credit exposures covered by the credit hedging instrument and the amount and conditions of coverage. Where applicable, it also models the premium or fees paid for credit protection.

Modeling Market and Macroeconomic Risk Sources

Under the IMA, the material sources of market risk that affect the value of the bank's trading book, foreign currency, and commodity positions must be identified and modeled as risk factors. The market risk factors should include factors that are deemed relevant for pricing of each type of financial instrument held in the portfolio, since the VaR and LTIRC metric calculations under the IMA depend upon accurate pricing of individual instruments.

Risk Factor Modeling

The Basel III IMA guidelines state that four general sources of market risk must be considered when identifying the risk factors relevant to a portfolio. These sources are interest rate risk, foreign exchange risk, equity price risk, and commodity price risk.

For interest rate risk, the IMR requires modeling of a set of tenor point risk factors for at least six tenor points for each yield curve, and modeling of different sets of tenor point risk factors for yield curves denominated in different currencies. In addition, tenor point yield spread curve risk factors must be modeled for different categories of financial instruments to capture the spread risk arising from less than perfectly correlated movements in rates associated with those categories, and interest rate volatility risk factors must be modeled for different types of interest rate options, different expiration tenors, and different exercise rates.

When the bank's trading book or banking book portfolio contains financial instruments denominated in different currencies, including foreign exchange derivative instruments, the portfolio will be subject to foreign exchange (FX) risk, and the IMA requires modeling of spot FX rate risk factors for spot FX rates between the bank's functional currency denomination and each foreign currency denomination. This allows economic values, cash flows, principal/notional balances, financial accounting income, expense, and book balances, and other monetary amounts of financial instruments representing market risk exposures to be translated into a common base (domestic) currency denomination. Spot FX rate risk factors are also required for the valuation of foreign exchange derivative instruments.

When a portfolio contains equity securities or equity derivative instruments, the portfolio will be subject to equity price risk, and the IMA requires equity market or equity security specific risk factors to be modeled for each equity market or equity security. At a minimum, a single equity market risk factor designed to capture market-wide movement in equity prices must be defined, but multiple equity market risk factors corresponding to price movements in different industry or other sectors can be defined. In either case, the beta-equivalents for each equity security relative to the market index must also be determined.

When a portfolio contains commodity positions or contracts, the portfolio will be subject to commodity price risk, and the IMA requires commodity specific risk factors to be modeled for each commodity.

The KRM solution supports the IMA requirement to model the market risk factors relevant to a particular analysis, such as interest rates at specified tenor points on a yield curve or spot FX rates. These risk factors are organized into a risk factor vector where each component risk factor models a specific source of risk to a portfolio. The risk factor vector describes the market and macroeconomic environment of a portfolio at a given point in time, and the values of the components of the risk factor vector are used as inputs to the valuation, cash flow, and income models in KRM applicable to financial instruments in a portfolio.

The KRM solution allows the user to define as many different risk factor vectors with a user-specified set of risk factor components as are required by the user to support differing views and analyses of a portfolio. Each component of a risk factor vector can be modeled as a specific source of risk to a portfolio. The KRM solution can model the following risk sources:

- Interest Rate at a Particular Tenor on a Specified Yield Curve Denominated in a Given Currency
- Underlying Risk Factor for a Dynamic Yield Curve Model for a Specified Yield Curve in a Given Currency
- Spot FX Rate Between a Base Currency Denomination and Another Currency Denomination
- Equity Market Index with a Specified Market Symbol in a Given Currency Denomination
- Black Scholes Implied Volatility for an Option Contract on an Underlying Asset, Rate Index, or Spot FX Rate
- Interest Rate Spread on a Specified Category of Bonds in a Specified Currency Denomination
- Interest Rate Spread on Bonds with a Specified Credit Rating
- Macroeconomic Risk Factors such as GDP Indices, Inflation Rates, or Housing Price Indices
- Performance Risk Factors for Industries, Asset Classes, or Other Market Segments
- Credit Risk Factors such as Obligor Default Intensity and Recovery Rate
- Counterparty-Specific Risk Factors Representing Idiosyncratic Risk

Risk factors are modeled collectively as a risk factor vector in the KRM solution so that correlations and other interdependencies between various risk sources can be reflected in portfolio analyses. Normally, only a subset of the risk factors in a risk factor vector affects the valuation of individual financial instruments in a portfolio. These component risk factors are referred to as pricing risk factors for each type of financial instrument. For example, an equity market index risk factor for a particular equity security market will affect the economic value of equity securities traded in that market and their

derivatives, but it will not affect the economic value of equity securities traded in other equity markets and their derivatives, and it will not affect the economic value of bonds or other instruments that are not impacted by equity market risk. Thus one or more of the component risk factors in the risk factor vector will be pricing risk factors relevant to financial instruments in a given asset class, but other risk factor components are included in the risk factor vector for valuation of other unrelated asset classes.

The risk factor vector used for portfolio analysis can include component risk factors that model specific macroeconomic factors as sources of risk to a portfolio. A large number of macroeconomic risk factors can be modeled in the KRM solution, and these factors can describe different macroeconomic sources of risk to a portfolio in a specific economy and the same source of risk in different economies. There is no limitation on the types of macroeconomic factors that can be modeled and included as component risk factors. Some of the types of risk factors that can be modeled in the KRM solution are:

- Consumer Price Index (CPI) for a specific country
- Gross Domestic Product (GDP) index for a specific country
- Purchasing Power Index (PPI) for a specific country
- Personal Consumption Index for a specific country
- Unemployment Rate for a specific country or geographical subdivision
- Industrial Production Index for a specific country
- Balance of Trade for a specific country
- Housing Starts Index for a specific country or geographical subdivision
- Home Sales Index for a specific country or geographical subdivision

In addition to these economy-wide macroeconomic factors, the KRM solution can also model a wide range of market-related macroeconomic factors, such as housing and commercial property price indices, oil, agricultural, and other commodity price indices, and the types of market risk factors discussed above.

Each macroeconomic factor modeled as a component risk factor in the KRM solution can describe a source of risk to financial instruments held in a portfolio. Some macroeconomic factors can directly affect the cash flows and economic values of one or more financial instruments in the portfolio, similarly to the market risk factors discussed above. For example, an inflation rate risk factor can be defined in terms of a particular CPI index, and inflation rate linked instruments held in a portfolio can be linked to that inflation rate risk factor so that future cash flows from these instruments vary as future inflation rates change.

Other macroeconomic factors may not directly affect financial instrument cash flows when this direct linkage is not manifested in specific financial instruments, but these factors may still represent a source

of risk to a portfolio through default and value recovery models. For example, when a relationship between default intensity and an underlying macroeconomic factor exists, changes in the macroeconomic factor will induce changes in default probabilities, and default probability changes will induce changes in economic values of financial instruments representing credit exposures. Default and value recovery models are further discussed in the section *Modeling Credit Behavior* below.

Yield Curve Modeling

Calculation of the VaR metrics required under the IMA involves valuation of the financial instruments in a portfolio at specific points in time. Since many financial instruments do not have active trading markets providing current market prices and market prices do not exist for future valuation dates, valuation of the financial instruments in a portfolio generally requires a model-based pricing methodology. Many financial instruments have contractually-defined future cash flows that provide the basis for pricing, and pricing methods for these instruments typically involve calculating the expected present value of these cash flows under a risk-neutral probability measure using discount rates obtained from a pricing yield curve applicable to each instrument. Thus a model for the pricing yield curve is required to provide these discount rates.

The KRM solution provides a flexible and sophisticated capability for modeling yield curves. Yield curves in the KRM solution define a parametric functional relationship between a specified (arbitrary) tenor and the yield, discount rate, or forward rate at that tenor. This functional relationship is intended to represent the interest rates at various tenors observed in the interest rate markets. The KRM solution allows many different yield curves to be defined by the user for different markets, such as LIBOR and US Treasury, and for specific currencies, such as USD, JPY, and EUR. Users can select the yield curve used by the pricing method applicable to each financial instrument in a portfolio. Users can also select the yield curve used to obtain reference rates for market indices required to simulate floating interest rates. All of the yield curves defined by a user can be simultaneously incorporated in the portfolio performance and risk analyses performed by the KRM Analytical Engine.

The KRM solution also allows yield spread curves to be defined that describe the functional relationship between tenor and yield spread. In addition, composite yield curves can be defined in the KRM solution by the superposition of a yield spread curve on a base yield curve. This allows a pricing yield curve for a specific category of financial instruments to be defined by the composition of a riskless yield curve and a yield spread curve reflecting the risk premium appropriate to that category of instruments. Additionally, composite yield curves can be defined by the composition of a riskless yield curve and a constant spread associated with each financial instrument referencing the yield curve, where the constant spread represents the risk premium appropriate to the financial instrument. Composite yield curves can also be defined in the KRM solution by a base yield curve and a yield spread model, where the yield spread model determines the yield spread as a function of the default probability of an obligor, the recovery rate on a financial instrument, and a liquidity premium. These composite yield curves can be thought of as credit-adjusted or counterparty-specific yield curves.

The KRM solution provides functionality to calibrate the parameters of the yield curve function for a yield curve on a given date using observed market yields or bond prices that are relevant to the yield curve for that date. This allows current and historical yield curves to be retained in the KRM Database.

Risk Factor Scenario Modeling

Deterministic changes in the risk factor vector can be modeled in the KRM solution as risk factor scenarios. Each user-defined risk factor scenario consists of specified changes to the value of one or more risk factor components of the portfolio risk factor vector. KRM allows changes to risk factor component values to be specified as absolute amounts, percentage changes, or changes sufficient to produce a targeted value. Risk factor scenarios can be either instantaneous or chronological (time-based). Instantaneous risk factor scenarios specify instantaneous changes to the associated values in the risk factor vector, while chronological risk factor scenarios specify a sequence of changes to the associated values in the risk factor vector at one or more discrete, user-specified future points in time. Users can specify as many deterministic risk factor scenarios as are required for analysis, and each scenario can be retained in the KRM Database for future reference and application.

Instantaneous risk factor scenarios are applied to KRM analyses that are performed at a single point in time, such as portfolio valuation. Chronological risk factor scenarios are applied to KRM analyses that are performed over one or more future simulation time periods, such as cash flow or income simulations. Since the IMA involves VaR and LTIRC analysis over one or more future simulation time periods, chronological risk factor scenarios are most relevant to calculating the IMA market risk capital requirement.

Modeling Credit Behavior

The Basel III market risk capital requirements include a charge for the specific risks associated with each market risk exposure. These specific risks include default and migration risk for the obligor of the market risk exposure. To incorporate these risks into the market risk capital requirements analysis, the obligors and/or counterparties of the market risk exposures in a portfolio must be identified and modeled, the default behavior of these obligors and/or counterparties must be modeled, and the recovery behavior of defaulted market risk exposures must be modeled.

The KRM solution provides a comprehensive and powerful framework for modeling default and recovery behavior, as discussed further below.

Obligor and Counterparty Modeling

The LTIRC default and migration risk metrics required by the IMA involve analysis of the default behavior of individual obligors and counterparties to financial instruments in a portfolio. Consequently, the identities of these obligors and counterparties must be known and their characteristics must be specified.

Default risk in the KRM solution is associated with individual obligors or counterparties that can potentially default on their contractual obligations. Since obligors/counterparties are the source of default risk, the KRM solution requires that each obligor/counterparty be uniquely identified and that the obligor/counterparty identifier be assigned as an attribute of all financial instruments representing credit exposures to the counterparty.

In addition, each obligor or counterparty has descriptive attributes that can be useful in performing portfolio analysis. These attributes include the geographical location and legal jurisdiction of the obligor or counterparty, financial statement information, and credit ratings that have been assigned by external or internal rating organizations. The KRM solution also allows additional user-defined descriptive attributes to be associated with obligors and counterparties. This permits each client to define categorizations that are useful in distinguishing between different types of obligors and counterparties. The KRM solution allows these descriptive attributes to be defined for individual obligors and counterparties as part of the obligor/counterparty model for each entity.

These obligor/counterparty attributes are primarily useful for grouping counterparties according to various characteristics and for aggregating and displaying aggregated and disaggregated analytical results, such as credit losses or VaR, for the resulting groups. Some obligor/counterparty attributes, such as certain financial ratios, may also be useful for estimating the parameters of obligor default models.

Obligor Default Behavior Modeling

The LTIRC default risk metrics required by the IMA require simulation of potential future obligor defaults. To perform the default simulation, default models applicable to each category of obligors are required.

The KRM solution offers three different default modeling frameworks: Default Intensity (DI), Merton Structural (MS), and State Transition (ST). All of these frameworks can be applied simultaneously to different categories of obligors. The DI framework also provides the basis for development of credit scoring models.

Default Intensity Models

The DI approach, which is frequently called the Reduced Form approach, describes default behavior as a stochastic duration process that results in a default event occurring at a random future time, where the intensity of the duration process can be contingent on one or more underlying risk factors. The relationship between the default intensity (or instantaneous default probability) and the underlying risk factors is described by a default intensity function, which is a logistic function of the risk factor variables whose coefficients can be estimated using logistic regression procedures. The structure of the default intensity model can be specified by the client, and the model coefficients can be estimated by a client using historical default and risk factor data or using credit-adjusted valuation models and observed market prices. Statistical performance metrics for the model, such as ROC ratios, are calculated by the calibration process. Alternatively, for listed corporate obligors or sovereign obligors, the coefficients can be obtained from Kamakura's KRIS default probability service.

Merton Structural Models

The MS approach describes default behavior as a stochastic asset value process that results in a default event when the asset value declines below some debt-related threshold. This approach is an updated version of the classical obligor default modeling paradigm originated by Robert Merton, which is based on an option theoretic view of obligor default. The option theoretic view treats default as a put option

on the assets of the obligor written by the debt holders in favor of the equity holders. The model parameters for this approach are the current asset value of the obligor, the volatility of the obligor's asset value, the risk-free rate of interest, and the debt-related default threshold (which is equivalent to an option exercise price). Each of these model parameters can be specified by the client, and they can be estimated using client-specific models and estimation procedures. Alternatively, for listed corporate obligors, the parameters can be obtained from Kamakura's KRIS default probability service.

State Transition Models

The ST approach describes default behavior as a stochastic state transition process that results in a default event when a transition to a default state occurs. This approach assumes that a set of ordered credit states exists and that each obligor counterparty or credit exposure has been assigned a current credit state. The set of credit states can correspond to a set of credit rating categories defined by an external rating agency, or they can be a client-specific set of rating categories for a particular category of obligors. Alternatively, the credit states can correspond to objective credit states, such as current, delinquent, severely delinquent, and defaulted.

Additionally, in the ST approach state transitions occur at future points in time according to a transition intensity between an obligor's current credit state and each of the credit states in the set. Transition intensities can be constant over time, which results in a constant transition probability, or in an enhanced version can be contingent on the values one or more underlying risk factors. The transition intensity matrix is calibrated to historical state transition frequencies transformed to an instantaneous rate using logarithmic matrix transformation. The transition frequencies for credit states corresponding to credit ratings defined by a rating agency can typically be obtained from the rating agency, while the transition frequencies for a set of internal credit rating categories or objective states must be estimated by the client based upon historical state transition experience.

Modeling Value Recovery for Defaulted Financial Instruments

The LTIRC default risk metrics required by the IMA require simulation of potential future value recovery for defaulted financial instruments so that the credit loss rates (LGDs) on these instruments can be determined. To perform the value recovery simulation, value recovery models applicable to various categories of financial instruments are required.

The KRM solution offers alternative models for value recovery on defaulted obligations to be specified and associated with individual financial instruments representing credit exposures in a portfolio. Value recovery models in KRM are recovery rate or process models that specify the fraction of the exposure at default (EAD) of an instrument that is recovered subsequent to a default of the obligor to the instrument. The difference between the EAD and the amount recovered is the economic loss given default (LGD) of the instrument.

Two value recovery modeling approaches are available in the KRM solution: the instantaneous recovery rate (IRR) approach and the value recovery process (VRP) approach. The KRM solution offers these alternative value recovery models so that clients can choose the model that is most useful and accurate given the historical loss data on defaulted obligations that is available to each client. The alternative model approaches can be employed simultaneously for different categories of credit exposures, and

clients can use multiple models for comparison of results. Kamakura believes this flexibility is advantageous to clients, since it does not require clients to employ a single model that may be inadequate in some contexts.

Instantaneous Recovery Rate Models

The traditional IRR approach assumes that recovery on a defaulted obligation occurs instantaneously at the time of default in an amount equal to a recovery rate multiplied by the credit exposure amount (EAD) at the time of default. The recovery rate for each model can be constant or a random value with a specified probability distribution. Different IR models can be defined and associated with various credit exposures in the portfolio. A constant recovery rate value or the parameters of the recovery rate probability distribution must be estimated for each IRR model, and these recovery rate values are typically calibrated to historical recovery rates on a sample of defaulted obligations with similar recovery characteristics. Clients can define the different categories of IRR models, estimate the recovery rate parameters for each IRR model, and associate a selected IRR model with one or more credit exposure instruments in a portfolio.

This relatively simple value recovery modeling approach allows different categories of credit exposures to have recovery rates that distinguish between different levels of seniority, different countries and economies, and different origination dates for credit exposures. It provides the first level of flexibility in LGD modeling in KRM.

Value Recovery Process Models

The value recovery process (VRP) approach assumes that recovery on a defaulted obligation occurs as a sequence of recovery events either at a fixed delay after the default time of a defaulted credit exposure or at random times subsequent to default. Each recovery event results in a random fractional recovery on the defaulted obligation. Different VRP models can be defined for different categories of credit exposures and different calibration data, and various credit exposures in a portfolio can be associated with one of the defined VRP models.

The interarrival times of the random recovery events for each VRP model are governed by a stochastic duration process described by a recovery event intensity function, which in an enhanced version can be a logistic function of underlying risk factors whose coefficients can be estimated using logistic regression procedures. The structure of the recovery event intensity model can be specified by the client, and the model coefficients can be estimated by a client using historical recovery timing and risk factor data reflecting the client's own experience or recovery information available from public sources.

The VRP approach also incorporates models for the amount of value recovered when a recovery event occurs. The fractional recovery rate for each recovery event can be a constant or alternatively a random variable that is described by a probability distribution function on the unit interval, such as a beta distribution. The parameters of the recovery rate probability distribution function must be calibrated by a client to observed historical fractional recovery.

Portfolio Valuation

The VaR and Stressed VaR metrics required by the IMA for capital requirement estimation involve valuation of financial instruments in a portfolio at the beginning and ending dates of the VaR analysis horizon. Likewise, the LTIRC migration risk metric required by the IMA involves valuation of financial instruments in a portfolio at the beginning and ending dates of the capital horizon.

Financial instruments with active trading markets can be priced using observed unit prices for those instruments in the market. However, these prices can only be observed currently and historically, while the IMA risk metrics require forward-looking prices that cannot be observed. Additionally, many portfolios are comprised of financial instruments with no active trading market, and current and historical prices generally cannot be observed for these instruments, except when the instruments were issued.

Since future economic values for financial instruments are required to calculate the IMA risk metrics, a pricing model or method for each type of financial instrument is needed to estimate the required economic values. The pricing method for each type of financial instrument will depend upon the pricing risk factors and pricing yield curves applicable to the instrument on the valuation dates. To assure that the economic values for different types of financial instruments are consistently estimated, the pricing models for the various instrument types must originate from a comprehensive, unified valuation framework in which a common collection of risk factors and yield curves drive the pricing results.

The KRM solution provides a comprehensive, unified framework of industry-standard, arbitrage-free pricing methods to determine the prices for individual financial instruments at current and future times. These pricing methods apply a common set of risk factor and yield curve models to describe the underlying sources of performance and risk across all types of financial instruments. The available pricing methods differ depending upon the form of financial instrument and the existence and structure of options embedded in the instrument.

Pricing Methods

The KRM solution provides analytical pricing methods for financial instruments with no embedded options or with European-style options on underlying assets with returns driven by geometric Brownian motion. The available analytical pricing methods include Discounted Cash Flow (e.g. for non-callable coupon bonds), Black-Scholes Option Pricing (e.g. for European-style options on bonds, rate swaps, rate caps, floors, and collars, spot FX, etc.), and Jamshidian Option Pricing (e.g. for European-style embedded interest rate options where interest rates follow an extended Vasicek term structure model). The analytical pricing methods are implemented by applying a set of financial instrument, yield curve, and risk factor inputs to a pricing formula and evaluating the formula using the KRM Analytical Engine.

Numerical pricing methods are generally required for financial instruments with uncertain future cash flows or with American- or Bermudan-style embedded options. The KRM solution incorporates several alternative numerical pricing methods to address this need, including the Binomial Tree Pricing, Trinomial Lattice Pricing, and Monte Carlo Pricing methods. These numerical pricing methods are parameterized to allow users to trade off calculation time for valuation accuracy. This allows financial

instruments that represent significant exposures to be priced more accurately than instruments offering lesser exposure while controlling the overall calculation time for pricing a portfolio.

The Binomial Tree Pricing method constructs a binary tree of values of an underlying asset at successive nodes representing time steps based upon a geometric Brownian motion model of the evolution of the asset's value. It applies the resulting binary tree to determine the value of the contingent cash flows of the financial instrument being priced at the terminal nodes of the tree, and it calculates the expected value of the contingent cash flows by recursively calculating expected discounted values at prior nodes until the tree root is encountered. The Binomial Tree Pricing method can be used in the KRM solution to price a variety of options, including American- and Asian-style options on spot FX rates, American-style options on futures contracts, American- and Bermudan-style options on bonds and other fixed-rate instruments.

The Trinomial Lattice Pricing method constructs a trinomial recombining tree or lattice (with three branches at each node) of values of an underlying asset at successive nodes representing time steps based upon a geometric Brownian motion model of the evolution of the asset's value. It applies the resulting trinomial tree to determine the value of the contingent cash flows of the financial instrument being priced at the terminal nodes of the tree, and it calculates the expected value of the contingent cash flows by recursively calculating expected discounted values at prior nodes until the tree root is encountered. The Trinomial Lattice Pricing method can be used in the KRM solution to price a variety of options, including embedded European-, American-, and Bermudan-style options on the remaining cash flows of fixed-rate instruments, freestanding European-, American-, and Bermudan-style option contracts on fixed-rate instruments, rate caps, floors, and collars, and rate swaptions and cancellable rate swaps.

The Monte Carlo Pricing method simulates a user-defined number of future sample paths of values of an underlying asset at successive user-defined time steps based upon a geometric or arithmetic Brownian motion model of the evolution of the asset's value. Each resulting asset value sample path is applied to determine the contingent cash flows of the financial instrument being priced, and the discounted value of the contingent cash flows is determined. The expected value of the discounted contingent cash flows is produced as the economic value of the financial instrument. The Monte Carlo Pricing method is used in the KRM solution to price all types of floating-rate instruments, fixed-rate instruments with prepayment options, rate caps, floors, and collars, rate swaptions and cancellable rate swaps, and European-, American-, and Asian-style FX options.

Default-Free vs. Credit-Adjusted Pricing

The pricing methods available in the KRM solution can be either default-free or credit-adjusted. Default-free pricing methods use a default-free pricing yield curve to determine the discount rates used to calculate the present value of future cash flows of financial instruments at various tenors. Credit-adjusted pricing methods use a credit-risky yield curve to obtain discount rates. As outlined above, credit-risky yield curves can be modeled in at least four distinct ways in the KRM solution: independently, as a composite curve incorporating a credit spread curve, as a composite curve incorporating an instrument-specific constant spread curve, and as a composite curve incorporating a credit spread model describing a variable spread curve.

When credit-risky yield curves are modeled independently, the curves incorporate the credit risk premium applicable to a particular category of obligors in the base yield curve. This requires that separate credit-risky yield curves be defined for each obligor category, such as for each credit rating category. For example, a separate curve would be defined for pricing all bonds issued by obligors with a 'BBB' credit rating.

When credit-risky yield curves are modeled as a composite curve incorporating a credit spread curve, a default-free yield curve is specified as the base yield curve, and a separate credit spread curve is defined for each obligor category having a different credit risk premium. This requires that separate credit spread curves be defined for each obligor category, such as for each credit rating category, but it allows interest rates generally to be modeled by a single default-free curve for each currency.

When credit-risky yield curves are modeled as a composite curve incorporating an instrument-specific constant spread curve, a default-free yield curve is specified as the base yield curve, and a constant spread percentage is defined for each financial instrument that references the composite curve. This allows a constant spread percentage representing a unique risk premium to be assigned to each financial instrument while using a single default-free curve for each currency for pricing.

When credit-risky yield curves are modeled as a composite curve incorporating a credit spread model, a default-free yield curve is specified as the base yield curve, and credit models are used to calculate the credit spread applicable to a particular obligor and credit exposure. The credit spread models are the default model for the obligor and the value recovery model for the credit exposure discussed above.

These alternative approaches to modeling the yield curve used for pricing of individual financial instruments can be applied to all of the pricing methods available in KRM to produce credit-adjusted economic values for the instruments, i.e. economic values that incorporate the credit risk premium demanded by investors in those instruments.

Valuation of Securitization Tranche Instruments

Under the IMA, some securitization positions can be included in the VaR and Stressed VaR metric results used to calculate the market risk capital requirement. Correlation trading securitization positions can also be included in the comprehensive risk metric used to calculate the market risk capital requirement. When these securitization positions are included in the IMA portfolio, the current and future economic values of these positions must be determined to calculate the VaR, Stressed VaR, and correlation risk metrics. This requires that securitization tranche instruments be modeled and priced consistently with other market risk exposures.

The KRM Analytical Engine calculates the economic value of securitization tranche instruments (securitized assets and synthetic CDOs) as the expected present value of projected future tranche cash flows by applying Monte Carlo pricing methods. The present value of future tranche cash flows is calculated using discount rates obtained from the pricing yield curve applicable to the securitization tranche instrument. Since securitization tranche instruments are normally issued by bankruptcy-remote entities, a default-free yield curve is frequently used to provide the discount rates. However, a credit-

risky yield curve can alternatively be used to provide the discount rates if some degree of credit risk is associated with the issuing entity.

The projected future tranche cash flows for each pricing sample path are simulated using the cash flow waterfall for the securitization structure to allocate aggregate projected future cash flows from the asset pool underlying the securitization tranche instrument for each pricing sample path. Aggregate projected future cash flows from the asset pool for each pricing sample path are derived by simulating the projected future cash flows for each asset instrument in the asset pool for each pricing sample path. The projected future cash flows for each asset instrument in the asset pool for each pricing sample path are determined by the cash flow model applicable to the instrument and the pricing sample path risk factors applied to the cash flow model.

The cash flow model for each asset instrument incorporates the contractual and behavioral features of the instrument. The cash flow model can simulate default-free cash flows for each asset instrument or alternatively can simulate the effects of obligor defaults on the cash flows of defaulted instruments subsequent to the default event. In the latter case, credit-risky cash flows are simulated using default models for obligors and value recovery models for defaulted instruments. These models are discussed in the *Obligor Default Behavior Modeling* and *Modeling Value Recovery for Defaulted Financial Instruments* sections above, and simulation of default events and value recovery processes is discussed in the section *Simulating Cash Flows and Income for Defaulted Instruments* below.

Risk Factor Vector and Yield Curve Simulation

Risk associated with the various financial instruments in a portfolio arises because of changes in risk factor values and yield curves over one or more consecutive future time periods. Under the IMA, these changes occur over the analysis horizons for calculation of the VaR, Stressed VaR, LTIRC default and migration, and comprehensive risk metrics.

These changes in risk factor values and yield curves can be simulated by the KRM Analytical Engine and accumulated over time to generate risk factor vector and yield curve sample paths. The resulting risk factor vector and yield curve sample paths can then be applied to the pricing, cash flow, and income models for financial instruments in the portfolio to obtain corresponding sample paths for the economic values, cash flows, and income produced for each instrument for future simulation periods. The risk factor vector and yield curve sample path values can also be retained in the KRM Database, where they can subsequently be retrieved for viewing and analysis.

To perform valuations and other point in time analytical processing tasks on a portfolio, the KRM Analytical Engine uses values of the risk factor vector and yield curves on the valuation date. The KRM Analytical Engine can also simulate the evolution of the risk factor vector over one or more future time periods to produce a risk factor vector and yield curve sample path when performing simulation-based analytical processing tasks. Depending upon the analytical processing task chosen by the user, the risk factor vector simulation can be performed either as a deterministic or stochastic simulation. To support calculation of the VaR, Stressed VaR, LTIRC default and migration, and comprehensive risk metrics, the KRM Analytical Engine performs a stochastic simulation. When performing a stochastic portfolio simulation, the KRM Analytical Engine uses one of two different approaches to risk factor simulation provided by the KRM solution: Historical/Imported Simulation or Monte Carlo Simulation.

Historical/Imported Simulation

The Historical/Imported Simulation method uses market rate and price data representing historical observations or simulated rates and prices from external sources to perform stochastic risk factor vector and yield curve simulation. The KRM solution can retain market price and rate data for bonds, equity securities, equity indices, futures contracts, spot FX rates, interest rate indices, and listed options as well as spreads for bonds and implied volatilities for listed and OTC options in the KRM Database. Macroeconomic data can also be retained in the KRM Database. These data can be retained on a daily basis or at any other frequency at which the market and macroeconomic data is available.

When performing Historical/Imported Simulation, the KRM Analytical Engine first assembles the market and economic data for each of the component risk factors in the risk factor vector over a specified time period and creates a set of risk factor vector observations. Historical/Imported Simulation samples this set of risk factor vector observations to obtain component risk factor values for each risk factor vector sample path. KRM allows the user to specify the range of dates for which historical/imported risk factor vector values are obtained and to select these values either sequentially over the data range or to sample the values randomly over the range.

The Historical/Imported Simulation functionality in the KRM Analytical Engine can sample the risk factor vector observations using one of five alternative sampling approaches:

1. The observations can be sampled sequentially in the order of their historical dates.
2. The observations can be sampled sequentially and the absolute changes between successive observations can be calculated. These observed changes are applied to the initial value of the risk factor vector successively to generate a risk factor vector sample path.
3. The observations can be sampled sequentially and the percentage changes between successive observations can be calculated. These observed changes are applied to the initial value of the risk factor vector successively to generate a risk factor vector sample path.
4. The observations can be sampled randomly, with each observation having an equal probability of being selected.
5. The observations can be sampled randomly, with each observation having an equal probability of being selected, and the percentage changes between successive observations can be calculated. These changes are applied to the initial value of the risk factor vector successively to generate a risk factor vector sample path.

Historical/Imported Simulation performs the sampling process for each simulation period in the simulation calendar. For single period simulation calendars, such as the horizon period for VaR analyses, this results in a sample path with one risk factor vector value at the end of the simulation period. For multi-period simulation calendars, such as a calendar consisting of 12 monthly periods used to perform multi-period credit loss simulations, this results in a sample path consisting of a set of successive risk factor vector values at the ends of the simulation periods.

The Historical/Imported Simulation sampling process is iterated to produce multiple risk factor vector sample paths. The number of iterations depends upon the sampling approach. For the sequential sampling approaches 1, 2, and 3 above, the number of iterations equals the number of observations in the of historical/imported risk factor vector values. For the random sampling approaches 4 and 5 above, the number of iterations is specified by the user as an input parameter for the Historical/Imported Simulation.

Yield curve evolution can be simulated in KRM using Historical/Imported Simulation of the risk factor vector. Two approaches for simulating yield curve evolution exist: Tenor Point and Term Structure. The Tenor Point approach requires specification of a set of tenor point risk factors for each yield curve and assembly of a collection of historical/imported yields at the specified tenor points into a set of risk factor vector observations. Tenor point yields are simulated using one of the Historical/Imported Simulation sampling processes described above to produce sample yields across the specified tenor points. Yields at arbitrary tenors on the evolved yield curve are then obtained by applying interpolation/extrapolation procedures to the sample tenor point yields for that yield curve.

The Term Structure approach requires specification of a term structure model for each yield curve. The term structure model for each yield curve is defined in terms of an underlying set of term structure factors that affect the future evolution of the level and shape of the entire yield curve. The Term Structure approach requires definition of the term structure factors as components of the risk factor vector. For example, the single-factor Hull and White (extended Vasicek) term structure model describes yield curve evolution in terms of the short rate of interest, so the short rate must be modeled as a component risk factor. Changes in the term structure factors are simulated using one of the Historical/Imported Simulation sampling processes described above to produce sample term structure factor values. Yields at standard tenors on the yield curve are calculated by applying the simulated term structure factor values to the term structure model. For example, simulated short rate changes can be applied to the Hull and White model to produce parallel shifts in the yield curve. Yields at arbitrary tenors on the evolved yield curve are then obtained by applying interpolation/extrapolation procedures to the sample standard tenor yields for that yield curve.

Monte Carlo Simulation

The Monte Carlo Simulation method uses sampled values of the risk factor vector obtained from a stochastic process model for the risk factor vector to perform stochastic risk factor vector and yield curve simulation. The vector stochastic process models describe the evolution of the risk factor vector for a portfolio over time as a set of successive changes to the value of the risk factor vector at the sampling times.

The KRM solution offers standard vector stochastic process modeling functionality to perform the Monte Carlo Simulation sampling process. These vector stochastic process models assume that the shocks to the interdependent component risk factors in the risk factor vector are either normally- or lognormally-distributed with a specified constant volatility and are correlated across the risk factors with specified correlations. The component risk factor volatilities are specified by the user by a volatility vector, and the risk factor correlations are specified by the user by a correlation matrix. Alternative volatility vectors and associated correlation matrices can be defined to describe different vector

stochastic process models for the risk factor vector. The KRM solution also allows independent components of the risk factor vector to be modeled using alternative distributions, including the Beta and Logistic functional forms and user-defined empirical distributions.

Calibration of the standard risk factor vector stochastic process model requires estimation of the volatility vector and correlation matrix for the random changes to risk factor vector values. To perform the calibration process, the KRM Analytical Engine assembles a set of risk factor vector observations as described above for Historical/Imported Simulation, and these observations are used as inputs to the statistical procedure for estimating the volatility vector and correlation matrix. Alternatively, the KRM solution allows users to import the volatility vectors and correlation matrices from external sources.

Monte Carlo Simulation performs the sampling process for each simulation period in the simulation calendar. For single period simulation calendars, such as the horizon period for VaR analyses, this results in a sample path with one risk factor vector value at the end of the simulation period. For multi-period simulation calendars, such as a calendar consisting of 12 monthly periods used to perform multi-period credit loss simulations, this results in a sample path consisting of a set of successive risk factor vector values at the ends of the simulation periods. The Monte Carlo Simulation sampling process is iterated to produce multiple risk factor vector sample paths. The number of iterations is specified by the user as an input parameter for the Monte Carlo Simulation.

Each risk factor vector sample produced by the Monte Carlo Simulation sampling process is generated using Monte Carlo simulation of the stochastic process model for the risk factor vector. This involves random sampling of the changes to the risk factor vector described by the vector stochastic process model. The random sampling process generates Normally-distributed random numbers for each component risk factor, and it generates risk factor vector samples through use of the Cholesky decomposition of the correlation matrix for the component risk factors. The sampled changes are then added to the initial risk factor vector value for a single period simulation calendar or to the initial or previous period risk factor vector value for a multi-period simulation calendar to produce each risk factor vector sample path.

Yield curve evolution can be simulated in KRM using Monte Carlo Simulation of the risk factor vector. Two approaches for simulating yield curve evolution exist: Tenor Point and Term Structure. The Tenor Point approach requires definition of a set of tenor point risk factors for each yield curve as components of the risk factor vector and specification of the tenor point risk factor volatilities and correlations in the volatility vector and correlation matrix for the risk factor vector. Tenor point yields are simulated using the Monte Carlo Simulation sampling process discussed above. Yields at arbitrary tenors on the evolved yield curve are then obtained by applying interpolation/extrapolation procedures to the sample tenor point yields for that yield curve.

The Term Structure approach requires specification of a term structure model for each yield curve. The term structure model for each yield curve is defined in terms of an underlying set of term structure factors that affect the future evolution of the level and shape of the entire yield curve. The Term Structure approach requires definition of these term structure factors as components of the risk factor vector. For example, the single-factor Hull and White (extended Vasicek) term structure model describes yield curve evolution in terms of the short rate of interest, so the short rate must be modeled as a component risk factor. Additionally, the term structure risk factor volatilities must be specified in the

volatility vector for the risk factor stochastic process, and the correlations among the term structure risk factors and between the term structure risk factors and other component risk factors in the risk factor vector must be specified in the correlation matrix for the risk factor vector stochastic process. Changes in the term structure factors are simulated using the Monte Carlo Simulation sampling process discussed above to produce sample term structure factor values. Yields at standard tenors on the yield curve are calculated by applying the simulated term structure factor values to the term structure model. For example, simulated short rate changes can be applied to the Hull and White model to produce parallel shifts in the yield curve. Yields at arbitrary tenors on the evolved yield curve are then obtained by applying interpolation/extrapolation procedures to the sample standard tenor yields for that yield curve.

Scenario-Based Simulation

The risk factor vector and yield curve sample paths generated by the Monte Carlo Simulation sampling process discussed above assume that the changes or logarithms of changes in the values of interdependent components of the risk factor vector are distributed according to a multivariate Normal distribution with a zero mean vector. This means that the simulated changes do not exhibit any trend over time that may exist in the actual market or macroeconomic factors being modeled. To address this issue, the KRM solution allows chronological risk factor scenarios to be applied to the Monte Carlo Simulation sampling process. Application of a chronological risk factor scenario modifies the risk factor vector sample values according to the types and amounts of changes specified in the scenario. For example, if the scenario specifies an absolute 100 bp upward change in the yield associated with a tenor point risk factor after 6 months and the sample value for that risk factor at the 6-month point in the Monte Carlo Simulation is 7 percent, the result of applying the scenario will be a value of 8 percent for the tenor point risk factor.

This scenario-based simulation functionality in KRM allows deterministic trends in the risk factor vector and yield curves to be modeled and simulated when performing stochastic simulations.

Value-at-Risk Analysis

The Value-at-Risk (VaR) metric for a portfolio of financial instruments is the basis for calculating the VaR and Stressed VaR market risk capital requirements under the IMA. VaR and other probabilistic risk metrics are defined based on changes in the economic values of financial instruments in a portfolio or subportfolio that result from random changes in underlying pricing risk factor vector values and yield curves over a specified analysis period. VaR measures the lower quantile of the value change distribution that will be exceeded with a given probability (confidence factor) based upon an instantaneous shock of the underlying pricing risk factor vector values and yield curves over the VaR analysis horizon.

KRM supports Value at Risk (VaR) measurement using the Variance-Covariance or Delta Normal method, Historical/Imported Simulation method, and Monte Carlo Simulation method. The Variance-Covariance method assumes that the portfolio economic value changes are distributed according to a Normal distribution, while the Historical/Imported and Monte Carlo simulation methods do not impose an assumption about the form of the distribution of economic value changes. One consequence is that the Variance-Covariance method is primarily applicable to portfolios composed of financial instruments

where economic value changes are approximately linear functions of the underlying pricing risk factor vector values and pricing yield curves.

Variance-Covariance (Delta Normal) VaR Method

For the Variance-Covariance method, KRM performs a full differential pricing of each financial instrument in a portfolio with respect to each underlying risk factor in the risk factor vector as a basis for determining the distribution of changes in portfolio economic value required to measure portfolio VaR. This provides more accurate deltas for the portfolio than the traditional risk bucketing approach. Differential pricing involves pricing of each financial instrument using the values of the pricing risk factors in the risk factor vector at the beginning of the horizon period together with a repricing of the instrument using the same pricing risk factor values plus a small (differential) change in those values. The difference between the economic values of each financial instrument produced by the differential change is then scaled by the square root of time over the VaR analysis horizon period to obtain the delta or differential change in economic value over the horizon period. KRM calculates the standard deviation of the portfolio value change distribution using the deltas for the financial instruments in the portfolio and the volatility vector and correlation matrix for the risk factor vector. The quantile of the portfolio value change distribution corresponding to the VaR confidence level can then be calculated using the resulting standard deviation value.

Historical/Imported Simulation Method

The KRM solution can perform Historical/Imported Simulation VaR analyses using the market and economic data retained in the KRM Database. Under the Historical/Imported Simulation method, the KRM Analytical Engine produces a set of risk factor vector and yield curve sample paths over a single simulation period corresponding to the VaR analysis horizon using the procedures described in the *Historical/Imported Simulation* section above. The number of these sample paths is determined either by the number of observations in the risk factor vector data set or by an iteration count supplied by the user, depending upon whether sequential or random sampling is employed. Each sample path consists of the risk factor vector value at the beginning of the VaR analysis horizon and the risk factor vector value at the end of the VaR analysis horizon together with the yield curves applicable to the portfolio at those times. The risk factor vector value and the yield curves at the beginning date of the VaR analysis horizon are the same across all sample paths, while the risk factor vector value and the yield curves at the ending date of the VaR analysis horizon will differ across sample paths because of the sampled changes in the risk factor values and yield curves.

To determine the economic value change for each sample path, the Historical/Imported Simulation method first calculates the economic value of each financial instrument in the portfolio for the beginning date of the VaR analysis horizon. The economic value change for each financial instrument in the portfolio on each sample path is then determined by calculating the economic value of that instrument at the ending date of the VaR analysis horizon and subtracting the previously calculated economic value at the beginning date of the VaR analysis horizon. The differential values of all financial instruments in the portfolio are then summed for each sample path to produce a differential value for the portfolio on that sample path. When the portfolio differential values across all sample paths are considered collectively, the collection provides a sample distribution of differential values for the portfolio across all risk factor vector and yield curve sample paths. The economic value of a financial

instrument on the beginning or ending date of the VaR analysis horizon is calculated using the pricing risk factor components of the risk factor vector and the pricing yield curve relevant to the type of that instrument on the beginning or ending date, respectively, and the economic value is calculated using the pricing method appropriate to the instrument.

The Historical/Imported Simulation method calculates the VaR metric for the portfolio by estimating the quantile of the sample distribution of differential values corresponding to the confidence level specified for the VaR metric. The quantile is estimated by ordering the portfolio differential values across all sample paths from highest to lowest and identifying the lowest differential value where the fraction of differential values that is higher than that value equals or exceeds the confidence level for the VaR metric.

Monte Carlo Simulation Method

The KRM solution can perform Monte Carlo Simulation VaR analyses using a risk factor vector stochastic process model and dynamic term structure model for each yield curve associated with a portfolio. Under the Monte Carlo Simulation method, the KRM Analytical Engine produces a set of risk factor vector and yield curve sample paths over a single simulation period corresponding to the VaR analysis horizon using the procedures described in the *Monte Carlo Simulation* section above. The number of these sample paths is determined by an iteration count supplied by the user. Each sample path consists of the risk factor vector value at the beginning of the VaR analysis horizon and the risk factor vector value at the end of the VaR analysis horizon together with the yield curves applicable to the portfolio at those times. The risk factor vector value and the yield curves at the beginning date of the VaR analysis horizon are the same across all sample paths, while the risk factor vector value and the yield curves at the ending date of the VaR analysis horizon will differ across sample paths because of the sampled changes in the risk factor values and yield curves.

To determine the economic value change for each sample path, the Monte Carlo Simulation method first calculates the economic value of each financial instrument in the portfolio for the beginning date of the VaR analysis horizon. The economic value change for each financial instrument in the portfolio on each sample path is then determined by calculating the economic value of that instrument at the ending date of the VaR analysis horizon and subtracting the previously calculated economic value at the beginning date of the VaR analysis horizon. The differential values of all financial instruments in the portfolio are then summed for each sample path to produce a differential value for the portfolio on that sample path. When the portfolio differential values across all sample paths are considered collectively, the collection provides a sample distribution of differential values for the portfolio across all risk factor vector and yield curve sample paths. The economic value of a financial instrument on the beginning or ending date of the VaR analysis horizon is calculated using the pricing risk factor components of the risk factor vector and the pricing yield curve relevant to the type of that instrument on the beginning or ending date, respectively, and the economic value is calculated using the pricing method appropriate to the instrument.

The Monte Carlo Simulation method calculates the VaR metric for the portfolio by estimating the quantile of the sample distribution of differential values corresponding to the confidence level specified for the VaR metric. The quantile is estimated by ordering the portfolio differential values across all sample paths from highest to lowest and identifying the lowest differential value where the fraction of

differential values that is higher than that value equals or exceeds the confidence level for the VaR metric.

Basic vs. Stressed VaR

The VaR-based market risk capital requirement for a portfolio under the Basel III IMA requires daily calculation of a basic VaR metric and a Stressed VaR metric for the portfolio. Both the basic VaR metric and the Stressed VaR metric can be calculated using the alternative VaR methods discussed above. However, the calibration process for the models used to calculate these VaR metrics differ. In particular, the historical risk factor and yield curve values for the basic VaR calibration process are observations for at least one year prior to the calibration date, so that the VaR metric is calculated based upon the most recent market and macroeconomic experience. On the other hand, the historical risk factor and yield curve values for the Stressed VaR calibration process are observations from a continuous 12-month period of significant financial stress relevant to the bank's portfolio. Thus the market and macroeconomic experience relevant to the Stressed VaR calibration process is typically prior to the most recent experience, and the bank must assess what continuous 12-month historical period best describes stressful market and macroeconomic conditions.

Since the KRM solution can use alternative risk factor and yield curve data sets as inputs to the calibration process for the risk factor vector and yield curve sampling procedures performed by VaR analysis, the user can import the alternative data sets required for IMA VaR and Stressed VaR calculations into the KRM Database. These alternative data sets can subsequently be used to provide sample observations for Historical/Imported Simulation sampling or for calibration of the stochastic process model used for Monte Carlo Simulation sampling, and the VaR and Stressed VaR metrics can be estimated from the distributions produced by these sampling procedures using the alternative data sets.

Multi-Period Cash Flow, Income, and Economic Value Simulation

The Long-Term Incremental Risk Charge (LTIRC) for a bank's portfolio under the IMA requires estimates of future credit losses arising from specific risks (default and migration) over a one-year capital horizon under the entire range of potential risk factor vector and yield curve sample paths. To estimate the distribution of the potential credit losses arising from default risk, a simulation of the credit losses resulting from a potential default of each financial instrument in the portfolio during the capital horizon under various risk factor vector and yield curve sample paths must be performed. Similarly, estimation of the distribution of potential credit losses or gains arising from migration risk involves simulation of the future default-free and credit-adjusted economic values of each financial instrument in the portfolio at the ending date of the capital horizon under various risk factor vector and yield curve sample paths as well as calculation of the default-free and credit-adjusted economic values of each financial instrument in the portfolio at the beginning date of the capital horizon.

In addition, since the LTIRC is based on the assumption of a constant level of risk over the capital horizon, the default and migration losses simulated over the capital horizon must incorporate simulated rebalancing (roll over) of the bank's trading positions in a manner that maintains the initial risk level, although the same positions do not necessarily have to be maintained throughout the capital horizon.

This assumption results in the need to simulate the future cash flows and income from all financial instruments covered by the LTIRC that will occur under the entire range of potential risk factor vector and yield curve sample paths and not just the future cash flows associated with defaulted financial instruments.

The KRM solution provides a comprehensive capability to perform portfolio economic value, cash flow and income/expense simulations over multiple future time periods. This capability is very flexible in allowing the client to determine the simulation calendar and accounting periods, the subportfolio to be analyzed, and the risk factor, yield curve, and behavioral models to be applied to the analysis.

Simulating Cash Flows and Income for Non-Defaulted Instruments

A simulation calendar in KRM defines a sequence of one or more consecutive future time periods over which the cash flow and income/expense simulations are performed. The number of days in each future time period (often referred to as an accounting period) can be independently defined so that different time periods can have different lengths. This allows users to define different simulation calendars for different purposes and permits the granularity of each simulation calendar to vary across time periods of differing tenors. For example, a simulation calendar can be defined where the first 30 consecutive time periods are one-day periods and where the next 11 consecutive time periods are one-month periods.

The multi-period simulation functionality in the KRM Analytical Engine simulates component cash flow and income/expense monetary amounts for each financial instrument using cash flow and income/expense models applicable to the instrument. Component cash flows correspond to cash flows of different types, such as principal vs. interest. Component income/expense amounts correspond to income and expense entries of different types, such as interest accruals vs. premium/discount amortization. The multi-period simulation functionality in the KRM Analytical Engine accumulates the cash flow and income/expense monetary amounts for each component of each financial instrument occurring during each simulation period and can retain these amounts in the KRM Database. This permits a very high degree of disaggregation of the overall portfolio cash flows and net income if required by the user. Alternatively, the cash flow and income/expense monetary amounts can be further aggregated across financial instruments in the same financial product category or specified subportfolio (sometimes referred to as a 'cut'), and the aggregated results for each component for each simulation period under each risk factor vector and yield curve sample path can be retained in the KRM Database. This allows highly disaggregated monetary amounts to be retained in the KRM Database for each financial instrument or alternatively permits intermediate levels of aggregated monetary amounts to be retained in the KRM Database, depending upon user preferences and requirements.

The component cash flow metrics that can be calculated by the KRM Analytical Engine for non-defaulted financial instruments include:

- Principal cash flows for bonds and other fixed- and floating-rate instruments.
- Prepaid principal cash flows for bonds and other fixed- and floating-rate instruments.
- Coupon interest cash flows for bonds and other fixed- and floating-rate instruments.

- Interest cash flows for rate swap and rate cap, floor, and corridor contract instruments.
- Dividend payments for equity securities.
- Option, forward contract, and commitment exercise cash flows.
- Premium cash flows on credit guarantees, credit default swaps, and other contingent liability instruments.
- Fees paid or received cash flows.

The component income/expense metrics that can be calculated by the KRM Analytical Engine for non-defaulted financial instruments include:

- Interest income and expense accrued over the simulation period for interest-bearing instruments based on the interest accrual convention (e.g. actual/365) applicable to the instrument, interest receipts or payments during the period, and the applicable coupon rates during the period.
- Amortization of acquisition premiums or discounts, capitalized fees, and other transactions costs under the effective interest method.
- Dividend income for equity securities during the simulation period.
- Gains or losses in fair value over the simulation period for instruments measured at fair value through profit and loss (or as trading securities) based on the fair value of the instrument measured at the beginning and end of the time period or upon acquisition or divestiture, as appropriate.
- Premium income or expense on credit guarantees, credit default swaps, and other contingent liability instruments during the simulation period.
- Fees earned or paid during the simulation period.
- Foreign exchange differences resulting from translation of monetary amounts for financial instruments from their contractual currency to their functional currency during the simulation period.

The cash flow and income metric values produced by the KRM Analytical Engine are calculated using cash flow and financial accounting methods for each of the different types of financial instruments modeled in the KRM solution. The cash flow and income methods for a specific financial instrument are selected based on that instrument's type, and the instrument's characteristics are defined by a set of instrument attribute values. The instrument attribute values include the contractual terms of the instrument, such as principal and book balances, coupon rates, coupon payment timing, frequency, and lag, etc. The instrument attribute values may also include references to models describing counterparty behavior, such as prepayments, dividend payments, or defaults.

The results produced by the cash flow and income models are also determined by the simulated market and economic environment during the time period for which the results are produced. The market and economic environment is described by the risk factor vector and yield curve sample path applied to the cash flow and income models. For example, the coupon rate for a floating-rate instrument is reset periodically based on the value of a simulated floating-rate index, which is a function of the yields at one or more tenor points on an associated simulated yield curve, so the coupon rate for the instrument is a function of the simulated interest rate environment when the rate is reset. Income and other financial accounting metrics are calculated using the measurement methods specified in the financial accounting standards applicable to the instrument.

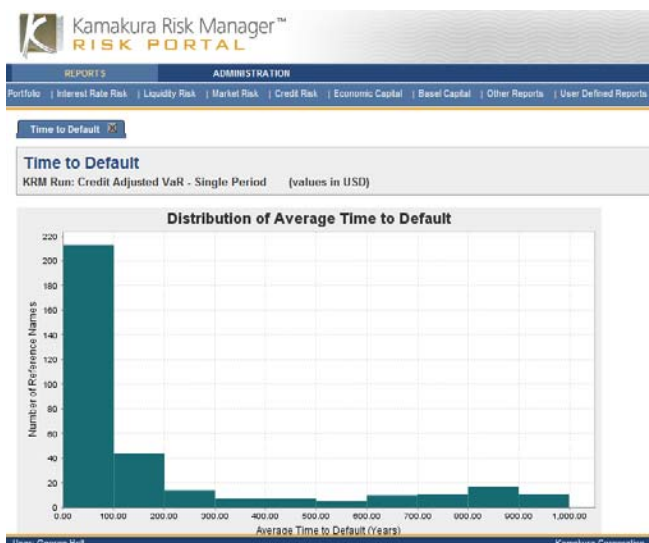
The KRM Analytical Engine retains the component cash flow and income values for each financial instrument during each accounting period over each simulation sample path in the KRM Database, where they can be viewed or used for subsequent analysis. Alternatively, the KRM Analytical Engine can simulate these values and aggregate them by financial product categories or specified subportfolios and can retain the results for the component aggregate in the KRM Database.

Simulating Cash Flows and Income for Defaulted Instruments

The cash flows and income simulated by the KRM Analytical Engine can include default- and migration-adjusted cash flows and income/expense if default and recovery models are incorporated in the simulation analysis. Default-adjusted cash flows (income) for a portfolio include cash flows (income) resulting from the occurrence of simulated future default events during the analysis horizon. Migration-adjusted cash flows (income) include cash flows (income) resulting from changes in credit-adjusted economic value over the analysis horizon arising from changes in default probabilities or recovery rates during that period.

Simulating Potential Obligor Default Events

Projection of future credit loss distributions for a portfolio depends upon projection of future default events for the obligor counterparties associated with credit exposure instruments in the portfolio. In general, the intensity of future obligor default events depends upon the simulated future market and economic environment, where a less favorable environment will tend to decrease the time to default of obligors. In the KRM solution, the default models discussed in the section *Obligor Default Behavior Modeling* above are used to describe the default behavior of obligor counterparties, and some of these models (DI and RT) can relate the intensity of default events or credit state transitions to values of the risk factor vector at future points in time. These models describe a stochastic default duration process for each obligor counterparty associated with financial instruments in the portfolio. The KRM Analytical Engine uses Monte Carlo simulation of these stochastic default duration processes to simulate future default events for each of the obligor counterparties. The simulated default events across all obligors associated with a portfolio produce a mixture distribution for default times, as shown in the report produced by the KRM Risk Portal below.



Propagating and Resolving Default Events

When a simulated default event for an obligor occurs, the KRM Analytical Engine propagates the default event to all credit exposure instruments in the portfolio where the defaulted obligor is the issuer or counterparty. In the KRM solution, the effect of the default event on each defaulted instrument depends upon a default performance model associated with the instrument. The default performance model specifies how the default is resolved and determines what the future cash flows and income and expenses of the defaulted instrument will be. The KRM solution provides several alternatives for modeling default resolution and the treatment of the future cash flows and income and expense.

The default resolution alternatives available in the KRM solution include: (i) *Balance Termination*: termination of the defaulted instrument contractual terms and substitution of an immediate demand for the outstanding notional principal balance of the instrument, which is typical of many loan contracts, (ii) *Value Termination*: termination of the defaulted instrument contractual terms and substitution of an immediate demand for the current economic value of the instrument at the time of the default event, which is typical of many derivative instruments, and (iii) *Continuation Accumulation*: continuation of the defaulted instrument contractual terms and accumulation and compounding of subsequent contractual principal and interest payments subsequent to the default event, which is sometimes applicable to loan contracts.

When *Balance Termination* is selected, the KRM Analytical Engine will calculate the outstanding principal balance of the defaulted instrument at the time of default as the EAD of the instrument. When *Value Termination* is selected, the KRM Analytical Engine will calculate the economic value of the remaining future cash flows of the defaulted instrument at the time of default as the EAD of the instrument. When *Continuation Accumulation* is selected, the EAD of the instrument can be considered the economic value of the instrument, although in this case credit losses do not depend upon this quantity.

Exposure at default (EAD) must generally be determined at the time a simulated default event occurs. This involves calculation of the outstanding balances of financial instruments with variable balances at

the time of default based on the contractual and behavioral principal or notional amortization of each instrument subsequent to its issuance. It also involves calculation of the economic replacement values of derivative instruments at the time of default of the counterparty. The KRM solution determines the EAD of a defaulted instrument based on these considerations. Clients can affect the EAD calculation through adjustments to the valuation model used to calculate the exposure amount of each instrument.

Simulating Value Recovery Processes

The default performance model for each defaulted financial instrument in the KRM solution also includes a value recovery process model for the instrument. The value recovery process models available in the KRM solution are discussed in section *Modeling Value Recovery for Defaulted Financial Instruments* above. Three types of value recovery models are available: (a) *Instantaneous*: recovery at the time of the default event, (b) *Deterministic Deferred*: recovery subsequent to the default event at a specified fixed time lag, and (c) *Stochastic Deferred*: recoveries at random times subsequent to the default event. These value recovery models describe the recovery behavior of defaulted financial instruments, which may be limited to recovery against the financial resources of the defaulting obligor or may also implicitly include recovery attributable to credit enhancements covering the defaulted financial instruments. As discussed in section *Market and Credit Risk Hedge Modeling* above, the KRM solution can also explicitly model the credit enhancements for individual financial instruments, and it can simulate value recovery from these credit enhancements subsequent to the financial instruments becoming defaulted.

Instantaneous Value Recovery

Instantaneous recovery is the most common assumption employed in current credit risk modeling. Instantaneous recovery applies to the *Balance Termination* and *Value Termination* default resolution alternatives above, and it assumes that the amount of value recovered is determined by the product of a recovery rate for the value recovery process and the EAD of the instrument. For instantaneous recovery, the KRM Analytical Engine calculates this recovery value and simulates a positive cash flow for the defaulted instrument in that amount at the default time. The KRM Analytical Engine will also calculate the credit loss amount for the instrument, which is equal to the book value of the instrument less the recovery value, and it will record this amount as a credit loss for the accounting period when the default event occurs. Subsequent to the default time, no other cash flows will be simulated for the defaulted instrument, and no other income or losses will be earned or incurred on the instrument.

Deterministic Deferred Value Recovery

Deferred recovery is sometimes a more realistic assumption for the value recovery process. The KRM solution can model deterministic deferred recovery for the *Balance Termination* and *Value Termination* default resolution alternatives above, and it assumes that the amount of value recovered is determined by the product of a recovery rate for the value recovery process and the EAD of the instrument.

For deterministic deferred recovery, the KRM Analytical Engine will calculate this recovery value and simulate a positive cash flow for the defaulted instrument in that amount at a time equal to the default event time plus a recovery lag time for the value recovery process. The KRM Analytical Engine will also calculate the credit loss amount for the instrument, which is equal to the book value of the instrument

at the time of the default event since no recoveries are made at that time, and it will record this amount as a credit loss for the accounting period when the default event occurs. This accounting period may be different from the accounting period when the recovery cash flow occurs, since credit impairment losses must be recognized at the time of default. When the recovery cash flow occurs, the KRM Analytical Engine will record a credit gain in an amount equal to the recovery amount for the accounting period when the recovery occurs. This accounting period is often subsequent to the accounting period when the credit loss for the defaulted instrument is recognized. Subsequent to the default time plus the recovery lag, no other cash flows will be simulated for the defaulted instrument, and no other income, credit losses, or credit gains will be earned or incurred on the defaulted instrument.

Stochastic Deferred Value Recovery

The exact time of value recoveries on a defaulted instrument is often not known, and the value recovery process for a defaulted instrument may involve multiple recovery events that result in uncertain amounts of value recovered. The KRM solution provides stochastic deferred recovery models to address this need.

A stochastic deferred value recovery model describes the value recovery process as a sequence of recovery events that occur with random interarrival times, where each recovery event results in a random value recovery amount. The random interarrival times of recovery events are described by a stochastic duration process, and the random recovery amounts for the recovery events are determined by a probability distribution of the fraction of the EAD of the defaulted instrument that is recovered. When the default performance model for a defaulted credit exposure instrument contains a stochastic deferred value recovery model, the KRM Analytical Engine will simulate the value recovery process as a sequence of recovery events that produce recovery amounts.

The KRM Analytical Engine uses Monte Carlo simulation techniques applied to a stochastic recovery duration model to simulate the random interarrival times of the recovery events. The KRM Analytical Engine uses Monte Carlo simulation techniques applied to a fractional recovery probability distribution to determine the portion of the EAD of the defaulted instrument that is recovered for each simulated recovery event. The KRM Analytical Engine simulates a positive cash flow for the defaulted instrument at the time of each recovery event in an amount equal to the product of the portion of the EAD obtained by sampling the fractional recovery distribution times the EAD of the instrument.

The KRM Analytical Engine will also calculate the credit loss amount for the instrument, which is equal to the book value of the instrument at the time of the default event since no recoveries are made at that time, and it will record this amount as a credit loss for the accounting period when the default event occurs. When a recovery cash flow occurs, the KRM Analytical Engine will record a recovery gain in an amount equal to the recovery amount for the accounting period when the recovery occurs. This can result in recovery gains being recorded in several accounting periods following the accounting period when the credit loss is recognized. This is the most realistic result for many loans and other credit exposures where delays in recovering value are frequent and the amount or value recovered is uncertain.

Credit Hedge Value Recovery

When a financial instrument is covered by a credit hedge, i.e. a funded, unfunded, or netted credit risk mitigation technique, an event of default by the obligor or counterparty of the financial instrument results in the contingent exercise of the contractual provisions of the credit hedge. For example, the default of the obligor on a collateralized loan will result in exercise of the contractual provisions of the collateral agreement (CA) instrument covering the loan, which will further result in the liquidation of the pool of collateral items underlying the CA instrument. Liquidation of the collateral pool provides cash proceeds to cover the losses on the covered credit exposure, which offsets the loss on the credit exposure incurred at the time the obligor defaults. Likewise, the default of the obligor on a guaranteed loan will result in exercise of the contractual provisions of the credit guarantee (CG) instrument covering the loan, which will further result in a demand for monetary reimbursement of the covered amount of the credit exposure from the third-party guarantor that is the counterparty to the credit guarantee. The guarantee proceeds offset the loss on the credit exposure incurred at the time the obligor defaults.

The KRM Analytical Engine can simulate the exercise of the beneficiary's rights under these credit hedges. Since in practice liquidation of a collateral pool or execution of a guarantee demand typically occurs with some delay subsequent to the default event, KRM uses a credit event value recovery process similar to the stochastic value recovery process described above for the timing and amounts of recoveries from credit h.

Simulating Future Economic Values for Non-Defaulted Instruments

The migration risk component of the LTIRC is based on the distribution of differential value changes for financial instruments in the bank's portfolio over the one-year capital horizon arising from changes in the credit quality of the obligors of the instruments under the full range of risk factor vector and yield curve sample paths. The portion of the value of a financial instrument that is attributable to credit risk (the credit discount) is the difference between the default-free economic value of the instrument and the credit-adjusted economic value of the instrument. The differential value change for a financial instrument that arises from changes in obligor credit quality over the one-year capital horizon is the change in the credit discount of the instrument over the one-year capital horizon. Thus the differential value change for a financial instrument arising from changes in obligor credit quality over the capital horizon is determined by the default-free and credit-adjusted economic values of the instrument at the beginning date of the horizon and the default-free and credit-adjusted economic values of the instrument at the ending date of the horizon.

The default-free and credit-adjusted economic values of the instrument at the beginning date of the capital horizon depend upon the risk factor vector and yield curve values at the beginning date, but the default-free and credit-adjusted economic values of the instrument at the ending date of the horizon depend upon the risk factor vector and yield curve values at the ending date, which depend upon the sample path under consideration. Consequently, the distribution of differential value changes for financial instruments over the one-year capital horizon arising from changes in credit quality require simulation of the future default-free and credit-adjusted economic values of the instruments under the full range of risk factor vector and yield curve sample paths.

The multi-period simulation functionality in the KRM Analytical Engine simulates future economic values for financial instruments using the pricing models applicable to each instrument. Default-free economic values are simulated when the pricing yield curve used for valuation is a default-free yield curve. Credit-adjusted economic values are simulated when the pricing yield curve used for valuation is a credit-adjusted yield curve that contains a credit spread appropriate to the obligor of the financial instrument being valued.

These economic values can be simulated for the ending date of each simulation period and as required at other times during each simulation period. This permits a very high degree of disaggregation of the overall portfolio economic value if required by the user. Alternatively, these economic values can be further aggregated across financial instruments in the same financial product category or specified subportfolio, and the aggregated economic value for each simulation period under each risk factor vector and yield curve sample path can be retained in the KRM Database. Additionally, these monetary amounts can be further aggregated across financial instruments in the same financial product category or specified subportfolio, and the aggregated results for each component for each simulation period under each risk factor vector and yield curve sample path can be retained in the KRM Database. This allows highly disaggregated economic values to be retained in the KRM Database for each financial instrument or alternatively permits intermediate levels of aggregated economic values to be retained in the KRM Database, depending upon user preferences and requirements.

Modeling and Simulating Dynamic Portfolio Strategies

The Long-Term Incremental Risk Charge (LTIRC) for a bank's portfolio under the IMA assumes a constant level of risk over the capital horizon, which implies that the bank rebalances (rolls over) its trading positions in a manner that maintains the initial risk level, as indicated by risk metrics such as VaR or the composition of the portfolio by credit rating and concentration. This means incorporating the effect of replacing positions whose credit characteristics have improved over the liquidity horizon with positions that have risk characteristics equivalent to those that the original position had at the start of the liquidity horizon. Rebalancing does not imply that the same positions will be maintained throughout the capital horizon.

Portfolio rebalancing requires a portfolio strategy, which is a plan for managing the composition of a portfolio in the future. Dynamic portfolio strategies involve plans where the future composition of a portfolio is determined by future market and macroeconomic conditions as well as the evolving composition of the portfolio at future points in time. Dynamic portfolio strategies contrast with static portfolio strategies, which fix the future composition of a portfolio at the current time. To analyze the effects of dynamic portfolio strategies, these strategies must be modeled, and the resulting models must be used to simulate changes in portfolio composition over a specified future analysis period.

The KRM solution provides a very powerful and flexible platform for modeling dynamic portfolio strategies and simulating these strategies to control future portfolio composition. Portfolio performance and risk analysis typically has an analysis horizon extending over several months or years, and the composition of subportfolios is not static over this period in the sense that the same financial instruments are always present in a subportfolio during the analysis horizon. Instead, subportfolio composition is dynamic because changes in the financial instruments held in the subportfolio change at

various points in time during the analysis horizon. These changes can have a significant impact on the portfolio performance and risk metric results for each subportfolio, and they need to be explicitly modeled and analyzed as part of the portfolio performance and risk analysis. In particular, cash flows produced by financial instruments in a portfolio should be considered in this analysis, and there are several sources of these cash flows that are relevant for analysis.

Contractual runoff of portfolio balances occurs because of the contractual terms of individual financial instruments in a portfolio. Many types of financial instruments, including bonds, loans, etc., have contractual maturity dates when an outstanding principal balance is paid to the investor and the contractual terms of the instrument expire. Some financial instruments have contractually-specified amortization schedules where a portion of the outstanding principal balance is paid to the investor periodically prior to maturity. Additionally, many types of financial instruments have embedded written call options where the portfolio receives or pays the outstanding principal balance of the instrument upon exercise of the option by the issuer and the contractual terms of the instrument expire upon option exercise. For these instruments, the portfolio will receive or pay monetary amounts prior to expiration, and these cash flows can be reinvested or refinanced during the analysis period or they can be distributed to or acquired from portfolio investors. Finally, cash flows from interest payments, fee payments, dividend distributions, leases, and other distributions from financial instruments also occur during the analysis period. These cash flows can also be reinvested or refinanced during the analysis period or they can be distributed to or acquired from portfolio investors.

In addition to reinvestment and refinancing of cash flows from financial instruments held in a portfolio at the beginning of an analysis period, the volume of investments in a portfolio can grow or shrink because of the demand of investors to invest new funds in a portfolio or to liquidate existing investments in a portfolio and withdraw the funds resulting from liquidation.

Modeling Dynamic Portfolio Strategies

The KRM solution incorporates functionality to model and simulate dynamic portfolio strategies. Dynamic portfolio strategies involve a continuous or periodic rebalancing of the composition of a portfolio over the analysis horizon. The KRM solution models dynamic portfolio strategies using a set of prioritized rebalancing conditions and associated rebalancing actions specified by the user. Individual rebalancing conditions are portfolio composition rules that apply to one or more financial products in the collection of financial products defined for portfolio analysis in the KRM solution. When a rebalancing condition is satisfied at a given time during the analysis horizon, the KRM Analytical Engine can perform a portfolio rebalancing action that results in changes in portfolio composition. The rebalancing actions include:

- Liquidation of a portion of the balances of financial instruments associated with financial products covered by the rebalancing condition.
- Curtailment of a portion of rollover cash flows reinvested in or refinanced by financial instruments associated with financial products covered by the rebalancing condition.
- Additional investment in or financing by financial instruments associated with financial products covered by the rebalancing condition.

Each portfolio rebalancing condition associated with a dynamic portfolio strategy in the KRM solution is a portfolio size and composition rule that references one or more financial products in the collection of financial products defined for portfolio analysis. When a rebalancing condition applies to more than one financial product, it specifies an allocation weight for each of the financial products covered by the rebalancing condition. This allocation weight is used to apportion new investments across the products.

Each portfolio rebalancing condition in the KRM solution specifies a target level for a particular type of balance for the financial products covered by the condition. Balance types for which target levels can be specified include period end and average principal or share balances over a period, period end amortized book balances, and period end fair values of financial instruments associated with the financial products covered by the condition. Target levels can be defined for existing financial product balances, rollover reinvestment balances, new investment balances, or a combination of these balances. Target levels can also be specified by the currency denomination of financial instruments associated with financial products covered by a rebalancing condition or across all currencies in which financial instruments are denominated. Target balance levels can be defined as absolute amounts, percentage or absolute changes relative to a beginning of period level, or by a product balance expression. A product balance expression is a mathematical formula that references initial, current, or lagged balances of one or more financial products.

Simulating Dynamic Portfolio Strategies

The KRM Analytical Engine uses the target balance levels associated with rebalancing conditions to determine which rebalancing actions are performed on the portfolio. The appropriate action is determined by comparing the target balance level for a financial product with the actual balance level for the product. The actual balance level for a financial product is the aggregate balance of the financial instruments in the portfolio that are associated with the financial product. When the actual balance level exceeds the target balance level, the KRM Analytical Engine will simulate liquidating transactions for the portfolio to the extent that the actual balance level is reduced to the target balance level. When the target balance level exceeds the actual balance level, the KRM Analytical Engine will simulate rollover reinvestment or refinancing activity to the extent that the actual balance level is increased to the target balance level or a lesser level. Finally, when the target balance level exceeds the actual balance level plus total rollover reinvestment or refinancing activity, the KRM Analytical Engine will simulate new investment or financing transactions if new investment or financing is part of the dynamic portfolio strategy. These portfolio rebalancing actions resulting from application of the rebalancing conditions are discussed in more detail below.

When multiple rebalancing conditions apply to a given financial product, application of the rebalancing conditions is prioritized by a unique priority level assigned to each rebalancing condition. The KRM Analytical Engine will apply the rebalancing conditions in order of highest to lowest priority when simulating dynamic portfolio strategies.

The KRM Analytical Engine can allocate simulated future component cash flows from the financial instruments associated with a financial product to reinvestment in or refinancing by new financial instruments associated with the same and/or other financial products. Component cash flows correspond to the different categories of cash flows associated with financial instruments in the KRM

solution. The component cash flows include principal cash flows, interest cash flows, principal at maturity cash flows, dividend cash flows, option premium cash flows, option exercise cash flows, fee cash flows, etc. Component cash flows can be either cash outflows from the portfolio or cash inflows into the portfolio, depending upon the circumstances.

The KRM Analytical Engine can reinvest or refinance individual simulated future cash flows, or alternatively cash flow amounts for a financial product can be aggregated across the portfolio and over a time period, and the accumulated cash flow amount can be reinvested or refinanced. When simulated cash flows for a financial instrument are denominated in a foreign currency, the cash flow amounts are converted to functional currency cash flows at the simulated spot FX rate between the foreign currency and the functional currency at the time the cash flow occurs.

The KRM solution allows individual cash flows or aggregated cash flows to be reinvested in or refinanced by financial instruments associated with one or more financial products, including the same financial product producing the cash flows. The portion of the individual or aggregated cash flow reinvested or refinanced in each financial product can be specified as a fixed percentage by the user, or alternatively this portion can be specified by calculating the value of an index function using factor values at the time the reinvestment occurs. The latter approach permits the allocation of the cash flows across financial products to vary with simulated market and macroeconomic conditions at the time when reinvestment occurs.

Incremental Risk Analysis

Under the IMA, incremental risk is the combination of the default risk and the migration risk of a bank's portfolio of debt instruments over a one-year capital horizon at a 99.9% confidence level, taking into account the liquidity horizons of individual positions or sets of positions, assuming a constant level of risk exposure over the capital horizon. The constant level of risk exposure is equivalent to rolling over the bank's trading positions in a manner that maintains the original risk exposure level. The liquidity horizon of a position or a set of positions is the time required for the bank to reduce its exposure to, or hedge all of its material risks of, the positions in a stressed market, which may not be less than the lower of three months or the contractual maturity of the position.

Default Risk Analysis

Calculation of the default risk capital requirement for the LTIRC requires estimation of the distribution of potential credit losses on financial instruments that become defaulted over the one-year capital horizon. The amount of credit losses depends upon the probabilities of individual obligors defaulting during the capital horizon, the fractional loss severity on financial instruments associated with a defaulting obligor when a default occurs, and the exposure amount or EAD of each defaulted instrument. These default probabilities, fractional loss severities, and EADs depend upon a collection of underlying risk factors and yield curves, which implies that default-related credit losses vary over time during the capital horizon.

Analysis of the default risk capital requirement for the LTIRC requires a multi-period stochastic simulation of potential counterparty defaults over a one-year capital horizon together with a simulation of credit losses on defaulted financial instruments. To perform the default simulation, default models describing the default behavior of the obligors of the financial instruments in the portfolio and recovery

models describing the value recovered from defaulted obligations are required. In general, these models will describe behavior as a function of underlying market and macroeconomic risk factors, implying that default intensities will vary over time as a function of simulated market and macroeconomic risk factors. The default models available in the KRM solution are discussed in the section *Obligor Default Behavior Modeling* above.

Counterparty defaults are simulated by the KRM Analytical Engine by performing a multi-period stochastic simulation where a collection of risk factor vector and yield curve sample paths are generated as described in the section *Risk Factor Vector and Yield Curve Simulation* above. For each risk factor vector and yield curve sample path, the KRM Analytical Engine simulates counterparty defaults using the default model appropriate to the counterparty as discussed in the section *Simulating Potential Obligor Default Events* above. When a simulated counterparty default occurs, the default event is propagated to the financial instruments where the counterparty is an obligor, and the default is resolved for each defaulted instrument. The KRM Analytical Engine performs default propagation and resolution as described in the section *Propagating and Resolving Default Events* above. Default resolution determines the exposure amount or EAD to which the loss and recovery models for each financial instrument are applied.

When a financial instrument becomes defaulted as a result of default propagation and resolution, the KRM Analytical Engine simulates financial losses and recovery gains and cash flows subsequent to the time of the default event using a value recovery model appropriate to each defaulted financial instrument. The value recovery models available in the KRM solution are discussed in the section *Modeling Value Recovery for Defaulted Financial Instruments* above, and the process of simulating value recoveries on defaulted financial instruments is discussed in the section *Simulating Value Recovery Processes* above.

In general, a defaulted instrument is considered fully impaired, and the KRM Analytical Engine simulates a credit loss equal to the book value of the instrument at the time of default less any immediate recovery gains incurred at that time. Immediate recovery gains are recovery amounts available from the counterparty at the time of default or recovery amounts immediately available from credit hedging instruments at the time of default. The KRM Analytical Engine can record the simulated credit loss amount for the financial instrument for the risk factor vector and yield curve sample path on which the default event was generated for the simulation (accounting) period when the default event occurs, and it can retain the recorded amount in the KRM Database.

The KRM Analytical Engine also simulates value recovery for defaulted financial instruments subsequent to the time of default. In particular, when Deterministic Deferred Value Recovery or Stochastic Deferred Value Recovery is modeled or when deferred Credit Hedge Value Recovery is modeled for a financial instrument, the KRM Analytical Engine will simulate one or more recovery events occurring subsequent to the time of default. For each simulated recovery event, the KRM Analytical Engine will simulate a fractional recovery rate, and a recovery amount equal to the fractional recovery rate times the EAD of the financial instrument is calculated. The KRM Analytical Engine can record the simulated recovery amount as a recovery gain and recovery cash inflow for the financial instrument for the risk factor vector and yield curve sample path on which the default event was generated for the simulation (accounting) period when the recovery event occurs, and it can retain the recovery gain and recovery cash inflow amounts in the KRM Database.

The multi-period stochastic simulation process performed by the KRM Analytical Engine outlined above produces credit loss and credit gain amounts for each financial instrument during each simulation (accounting) period in the simulation calendar for each risk factor vector and yield curve sample path. These credit gains and losses can be aggregated across all financial instruments in the portfolio to provide net credit loss amounts for each simulation (accounting) period in the simulation calendar for each risk factor vector and yield curve sample path. The aggregated net credit loss amounts can be accumulated across the simulation periods in the simulation calendar to produce an accumulated net credit loss amount for each risk factor vector and yield curve sample path. When considered across all risk factor vector and yield curve sample paths, these accumulated net credit loss amounts provide a sample distribution of net credit losses for the portfolio for the simulation calendar.

The multi-period stochastic simulation process performed by the KRM Analytical Engine can be configured to provide the credit loss distribution required to calculate the default risk capital requirement under the IMA. In particular, a simulation calendar consisting of 12 successive one-month simulation periods can be defined and a subportfolio consisting of the bank's debt instruments can be selected so that the simulation process is performed over the required capital horizon and incorporates the required financial instruments. This provides a sample credit loss distribution as a basis for calculating the probabilistic default risk metric required by the IMA.

The probabilistic default risk metric is essentially a credit-loss-at-risk (CLaR) metric that is calculated by estimating the quantile of the sample credit loss distribution corresponding to the confidence level required by the IMA (99.9%). The quantile is estimated by ordering the subportfolio credit loss amounts across all sample paths from highest to lowest and identifying the highest credit loss amount where the fraction of credit loss amounts that is lower than that value equals or exceeds the confidence level for the default risk metric.

The probabilistic default risk metric required by the IMA must be calculated based upon a constant level of risk over the capital horizon, taking into account the liquidity horizons of individual positions or sets of positions, and this requirement imposes additional demands on the multi-period stochastic simulation process. In particular, dynamic portfolio strategies must be modeled that periodically liquidate financial instruments at their liquidity horizon and reinvest the cash inflows from the liquidations in new financial instruments with comparable risks to corresponding initial positions in similar instruments.

To satisfy the constant risk level requirement, these dynamic portfolio strategies must be modeled using the modeling functionality discussed in section *Modeling Dynamic Portfolio Strategies* above. These dynamic portfolio strategy models must also be incorporated into the multi-period stochastic simulation process so that portfolio composition is modified at the end of each simulation period in the simulation calendar according to these models, as discussed in the section *Simulating Dynamic Portfolio Strategies* above.

An important implication of the requirement to liquidate individual financial instruments at their liquidity horizons is that the economic value of each instrument must be estimated upon liquidation so that the cash proceeds from liquidation can be determined as the basis for rollover under the modeled dynamic portfolio strategy. This means that the initial financial instruments or their rollover substitutes

will have to be priced at the applicable liquidity horizons. Consequently, some portion of the financial instruments will be priced at the end of each simulation period in the simulation calendar. For example, the simulation calendar required for default risk analysis under the IMA would require pricing of some financial instruments at the end of each of the 12 months in the calendar.

The relatively high confidence level required by the IMA for default risk (99.9%) effectively imposes an additional requirement on the multi-period simulation. In particular, the credit loss sample distribution for the subportfolio will likely require 10,000 or more sample points to assure reliability and stability of the default risk metric, since 10,000 sample points provides an expectation that 10 sample points will exceed the confidence level quartile. Together with the need to perform a multi-period simulation incorporating the dynamic portfolio strategies discussed above, this will necessitate substantially greater computational effort than the single-period simulation requirement for the VaR and Stressed VaR analyses discussed previously.

Migration Risk Analysis

Calculation of the migration risk capital requirement for the LTIRC requires estimation of the distribution of differential value changes for financial instruments in the bank's portfolio over the one-year capital horizon arising from changes in the credit quality of the obligors of the instruments under the full range of risk factor vector and yield curve sample paths. As discussed in the section *Simulating Future Economic Values for Non-Defaulted Instruments* above, this is equivalent to estimating the distribution of changes in the credit discount over the one-year capital horizon under the full range of risk factor vector and yield curve sample paths, and it requires simulation of the future default-free and credit-adjusted economic values of the instruments in the bank's portfolio under the full range of risk factor vector and yield curve sample paths.

Thus analysis of the migration risk capital requirement for the LTIRC requires a multi-period stochastic simulation of the future default-free and credit-adjusted economic values of the instruments in the bank's portfolio under the full range of risk factor vector and yield curve sample paths together with calculation of default-free and credit-adjusted economic values at the beginning date of the simulation calendar. Both default-free and credit-adjusted economic values depend upon the risk factor vector values at the beginning and end of the capital horizon. Default-free economic values depend upon the default-free yield curves at the beginning and end of the capital horizon, while credit-adjusted economic values depend upon the credit-adjusted yield curves at the beginning and end of the capital horizon. As discussed in the section *Default-Free vs. Credit-Adjusted Pricing* above, the credit-adjusted yield curves can depend upon the credit risk models discussed in section *Modeling Credit Behavior* above.

Future economic values are simulated by the KRM Analytical Engine by performing a multi-period stochastic simulation where a collection of risk factor vector and yield curve sample paths are generated as described in the section *Risk Factor Vector and Yield Curve Simulation* above. For each risk factor vector and yield curve sample path, the KRM Analytical Engine simulates the future economic value of each financial instrument as described in the section *Simulating Future Economic Values for Non-Defaulted Instruments* above. To produce default-free economic values, the multi-period simulation is performed using default-free yield curves to price each financial instrument. To produce credit-adjusted economic values, the multi-period simulation is performed using credit-adjusted yield curves to price

each financial instrument. The two multi-period stochastic simulations are performed using the same set of risk factor vector and yield curve sample paths.

The two multi-period stochastic simulation processes performed by the KRM Analytical Engine outlined above produce future default-free and credit-adjusted economic values, respectively, for each financial instrument at the ending date of the simulation calendar for each risk factor vector and yield curve sample path. For each financial instrument on each sample path, the credit discount amount for the ending date of the simulation calendar is calculated by subtracting the credit-adjusted economic value from the default-free economic value.

The default-free and credit-adjusted values of each financial instrument are also calculated at the beginning date of the simulation calendar using the risk factor vector value and default-free and credit-adjusted yield curves, respectively, for the beginning date applied to the pricing method appropriate to each financial instrument, as discussed in the section *Portfolio Valuation* above. For each financial instrument, the credit discount amount for the beginning date of the simulation calendar is calculated by subtracting the credit-adjusted economic value from the default-free economic value.

The change in the credit discount over the simulation calendar is calculated for each financial instrument and each risk factor vector and yield curve sample path by subtracting the credit discount at the beginning date of the simulation calendar from the credit discount at the ending date of the simulation calendar.

These credit discount amounts can be aggregated across all financial instruments in the portfolio to provide net credit discount change amounts for each risk factor vector and yield curve sample path. When considered across all risk factor vector and yield curve sample paths, these net credit discount change amounts provide a sample distribution of credit discount changes for the portfolio over the simulation calendar.

The multi-period stochastic simulation processes performed by the KRM Analytical Engine can be configured to provide the credit discount change distribution required to calculate the migration risk capital requirement under the IMA. In particular, a simulation calendar consisting of 12 successive one-month simulation periods can be defined and a subportfolio consisting of the bank's debt instruments can be selected so that the simulation process is performed over the required capital horizon and incorporates the required financial instruments. This provides a sample credit discount change distribution as a basis for calculating the probabilistic migration risk metric required by the IMA.

The probabilistic migration risk metric is essentially a credit-discount-change-at-risk (CDCaR) metric that is calculated by estimating the quantile of the sample credit discount change distribution corresponding to the confidence level required by the IMA (99.9%). The quantile is estimated by ordering the subportfolio credit discount change amounts across all sample paths from highest to lowest and identifying the highest credit discount change amount where the fraction of credit discount change amounts that is lower than that value equals or exceeds the confidence level for the migration risk metric.

The probabilistic migration risk metric required by the IMA must be calculated based upon a constant level of risk over the capital horizon, taking into account the liquidity horizons of individual positions or

sets of positions, and this requirement imposes additional demands on the multi-period stochastic simulation process. In particular, dynamic portfolio strategies must be modeled that periodically liquidate financial instruments at their liquidity horizon and reinvest the cash inflows from the liquidations in new financial instruments with comparable risks to corresponding initial positions in similar instruments.

To satisfy the constant risk level requirement, these dynamic portfolio strategies must be modeled using the functionality discussed in the section *Modeling Dynamic Portfolio Strategies* above. These dynamic portfolio strategy models must also be incorporated into the multi-period stochastic simulation processes so that portfolio composition is modified at the end of each simulation period in the simulation calendar according to these models, as discussed in the section *Simulating Dynamic Portfolio Strategies* above.

An important implication of the requirement to liquidate individual financial instruments at their liquidity horizons is that the economic value of each instrument must be estimated upon liquidation so that the cash proceeds from liquidation can be determined as the basis for rollover under the modeled dynamic portfolio strategy. This means that the initial financial instruments or their rollover substitutes will have to be priced at the applicable liquidity horizons. Consequently, some portion of the financial instruments will be priced at the end of each simulation period in the simulation calendar. For example, the simulation calendar required for migration risk analysis under the IMA would require pricing of some financial instruments at the end of each of the 12 months in the calendar.

The relatively high confidence level required by the IMA for migration risk (99.9%) effectively imposes an additional requirement on the multi-period simulation. In particular, the credit discount change sample distribution for the subportfolio will likely require 10,000 or more sample points to assure reliability and stability of the migration risk metric, since 10,000 sample points provides an expectation that 10 sample points will exceed the confidence level quartile. Together with the need to perform a multi-period simulation incorporating the dynamic portfolio strategies discussed above, this will necessitate substantially greater computational effort than the single-period simulation requirement for the VaR and Stressed VaR analyses discussed previously.

Comprehensive Risk Analysis

Under the IMA, comprehensive risk represents an estimate of all price risks of the bank's portfolio of correlation trading positions over a one-year capital horizon at a 99.9% confidence level, assuming a constant level of risk exposure over the capital horizon. Correlation trading positions are certain securitization positions or hedges thereof as defined in section *Comprehensive Risk Capital Requirement* above. The constant level of risk exposure is equivalent to rolling over that the bank's correlation trading positions in a manner that maintains the original risk exposure level. The liquidity horizon of a position or a set of positions is the time required for the bank to reduce its exposure to, or hedge all of its material risks of, the positions in a stressed market, which may not be less than the lower of three months or the contractual maturity of the position.

Analysis of comprehensive risk for the Comprehensive Risk Capital Requirement requires estimation of the distribution of potential economic value losses on securitization positions arising from changes in pricing factors on the underlying exposures or the securitization deal structure over the one-year

horizon. Pricing factors include risk factors, yield curves, credit spreads, default events, recovery rates, and other material risk sources. Since the performance of a securitization position is substantially dependent upon the performance of the underlying exposures and the correlations among the exposures, a detailed analysis of the default-adjusted performance of each underlying exposure is essential to analyzing the comprehensive risk of each securitization position.

Calculation of the comprehensive risk capital requirement requires estimation of the distribution of economic value differentials for securitization tranche instruments in the bank's portfolio over the one-year capital horizon arising from changes in the pricing factors affecting the instruments under the full range of risk factor vector and yield curve sample paths. Economic value differentials are the difference between the economic value of each securitization tranche instrument at the ending date of the simulation calendar and the economic value of the instrument at the beginning date of the calendar. Consequently, estimation of the distribution of economic value differentials for the securitization tranche instruments in the bank's portfolio requires simulation of the economic value of each instrument at the beginning and ending dates of the simulation calendar under the full range of risk factor vector and yield curve sample paths.

The KRM Analytical Engine performs a multi-period stochastic simulation of the economic values of the securitization tranche instruments in the bank's portfolio at the ending date of the simulation calendar under the full range of risk factor vector and yield curve sample paths to obtain the economic value differentials for each sample path. This simulation process is similar to the economic value simulation process discussed in the section *Simulating Future Economic Values for Non-Defaulted Instruments* above. The economic value of each securitization tranche instrument is also calculated at the beginning date of the simulation calendar using the risk factor vector value and yield curve for the beginning date applied to the pricing method appropriate to the securitization tranche instrument, as discussed in the section *Valuation of Securitization Tranche Instruments* above. For each securitization tranche instrument, the economic value differential for each securitization tranche instrument on each risk factor vector and yield curve sample path over the capital horizon is calculated by subtracting the economic value of the instrument on the ending date of the simulation calendar from the economic value of the instrument on the beginning date of the simulation calendar for that sample path.

The economic value of a securitization tranche instrument (e.g. securitized assets and synthetic CDOs) for a particular pricing date is usually calculated as the expected present value on the pricing date of projected future tranche cash flows using discount rates obtained from the pricing yield curve applicable to the securitization tranche instrument across all potential pricing sample paths, as discussed in section *Valuation of Securitization Tranche Instruments* above. Pricing sample paths consist of the pricing risk factors, yield curves, credit spreads, default events, recovery events and recovery rates required to simulate the performance of the asset pool underlying a securitization tranche instrument and to discount the tranche cash flows. The KRM Analytical Engine simulates the projected future tranche cash flows for each pricing sample path using the cash flow waterfall for the securitization structure to allocate aggregate projected future asset pool cash flows for each pricing sample path. Aggregate projected future asset pool cash flows for each pricing sample path are simulated by simulating the projected future cash flows for each asset instrument in the asset pool for each pricing sample path. The projected future cash flows for each asset instrument in the asset pool for each pricing sample path are determined by the cash flow model applicable to the instrument and the pricing sample path risk factors applied to the cash flow model.

The cash flow model for each asset instrument in the asset pool incorporates the contractual and behavioral features of the instrument and the pricing factors applicable to the instrument. The cash flow model simulates the contractual cash flows when the asset instrument has not defaulted and the effects of obligor defaults on the cash flows subsequent to an instrument becoming defaulted. In the latter case, credit-risky cash flows are simulated using default models for obligors and value recovery models for defaulted instruments. These models are discussed in the *Obligor Default Behavior Modeling* and *Modeling Value Recovery for Defaulted Financial Instruments* sections above, and simulation of default events and value recovery processes is discussed in the section *Simulating Cash Flows and Income for Defaulted Instruments* above.

The economic value differentials produced by the stochastic simulation for a given risk factor vector and yield curve sample path can be aggregated across all securitization tranche instruments in the portfolio to provide net economic value differentials for the portfolio on the sample path. When considered across all risk factor vector and yield curve sample paths, these net economic value differentials provide a sample distribution of net differential economic value changes for the portfolio over the simulation calendar.

The multi-period stochastic simulation processes performed by the KRM Analytical Engine can be configured to provide the economic value differential distribution required to calculate the comprehensive risk capital requirement under the IMA. In particular, a simulation calendar consisting of 12 successive one-month simulation periods can be defined and a subportfolio consisting of the bank's securitization tranche instruments can be selected so that the simulation process is performed over the required capital horizon and incorporates the required financial instruments. This provides a sample differential economic value distribution as a basis for calculating the probabilistic comprehensive risk metric required by the IMA.

The probabilistic comprehensive risk metric is essentially a differential-economic-value -at-risk (DEVaR) metric that is calculated by estimating the quantile of the sample differential economic value distribution corresponding to the confidence level required by the IMA (99.9%). The quantile is estimated by ordering the subportfolio differential economic values across all sample paths from highest to lowest and identifying the highest differential economic value where the fraction of differential economic values that is lower than that value equals or exceeds the confidence level for the comprehensive risk metric.

The probabilistic comprehensive risk metric required by the IMA must be calculated based upon a constant level of risk over the capital horizon, taking into account the liquidity horizons of individual positions or sets of positions, and this requirement imposes additional demands on the multi-period stochastic simulation process. In particular, dynamic portfolio strategies must be modeled that periodically liquidate securitization tranche instruments at their liquidity horizon and reinvest the cash inflows from the liquidations in new securitization tranche instruments with comparable risks to corresponding initial positions in similar securitization tranche instruments.

To satisfy the constant risk level requirement, these dynamic portfolio strategies must be modeled using the modeling functionality discussed in section *Modeling Dynamic Portfolio Strategies* above. These dynamic portfolio strategy models must also be incorporated into the multi-period stochastic simulation

processes so that portfolio composition is modified at the end of each simulation period in the simulation calendar according to these models, as discussed in the section *Simulating Dynamic Portfolio Strategies* above.

An important implication of the requirement to liquidate individual securitization tranche instruments at their liquidity horizons is that the economic value of each instrument must be estimated upon liquidation so that the cash proceeds from liquidation can be determined as the basis for rollover under the modeled dynamic portfolio strategy. This means that the initial securitization tranche instruments or their rollover substitutes will have to be priced at the applicable liquidity horizons. Consequently, some portion of the securitization tranche instruments will be priced at the end of each simulation period in the simulation calendar. For example, the simulation calendar required for comprehensive risk analysis under the IMA would require pricing of some securitization tranche instruments at the end of each of the 12 months in the calendar.

The relatively high confidence level required by the IMA for comprehensive risk (99.9%) effectively imposes an additional requirement on the multi-period simulation. In particular, the economic value differential distribution for the subportfolio will likely require 10,000 or more sample points to assure reliability and stability of the comprehensive risk metric, since 10,000 sample points provides an expectation that 10 sample points will exceed the confidence level quartile. Together with the need to perform a multi-period simulation incorporating the dynamic portfolio strategies discussed above, this will necessitate substantially greater computational effort than the single-period simulation requirement for the VaR and Stressed VaR analyses discussed previously.

The multi-period stochastic simulation processes performed by the KRM Analytical Engine to calculate the comprehensive risk metric capture the significant risks required by the IMA. In particular:

- The cumulative risk arising from multiple defaults, including the ordering of defaults, in tranching products.

The pricing factor simulations performed by the KRM Analytical Engine to estimate the economic value of securitization tranche instruments simulate default events for the obligors of the asset instruments underlying each instrument that result in termination of contractual cash flows and simulation of recovery process cash flows. The sequence of the default events and the modifications of asset instrument cash flows that result from these events modify the aggregate cash flows from the asset pool in a cumulative fashion and can thereby produce variation and risk in securitization tranche cash flows.

- Credit spread risk, including the gamma and cross-gamma effects.

The securitization tranche instrument pricing performed by the KRM Analytical Engine fully reflects the credit spreads on the asset instruments underlying the securitization tranche instrument, since asset instrument credit spreads are determined by the default and recovery models associated with each asset instrument. Consequently, any changes in the credit spread on an underlying asset instrument caused by changes in default probabilities or recovery rates will result in changes in securitization tranche prices. Thus it is straightforward to determine the first-order (delta) and second-order (gamma and cross gamma) effects of changes in asset instrument credit spreads on

the price of a securitization tranche instrument where the asset instrument underlies the securitization tranche instrument.

- Volatility of implied correlations, including the cross effect between spreads and correlations.

Implied correlations between the default times of different obligors associated with different asset instruments in the asset pool underlying a securitization tranche instrument can be explicitly modeled in the KRM solution, since the default models used in KRM can be structured to depend upon one or more underlying risk factors, and the risk factors can be correlated. Changes in the underlying risk factors can change the default or credit state transition intensities for different obligors, and changes in the default or credit state transition intensities result in changes in the timing of defaults and their correlation. These changes also will affect the credit spreads on the asset instruments underlying a securitization tranche instrument.

- Basis risk, including both
 - the basis between the spread of an index and those of its constituent single names; and
 - the basis between the implied correlation of an index and that of bespoke portfolios.

The KRM solution allows securitization tranche instruments on both an underlying index and on an underlying pool of single-name asset instruments to be modeled, simulated, and priced. In particular, the credit spreads on the index and on the constituent single-name asset instruments are explicitly modeled using default and recovery models. This allows the basis between a securitization tranche instrument on an underlying index and a securitization tranche instrument on an underlying pool of single-name asset instruments to be analyzed through simulation.

- Recovery rate volatility, as it relates to the propensity for recovery rates to affect tranche prices.

Value recovery process models can be associated with the asset instruments underlying a securitization tranche instrument, and these models can be used to simulate recovery events and fractional recovery rates. These models allow recovery rates to be random both in time and amount, which introduces recovery rate volatility into the pricing of securitization tranche instruments.

- To the extent the comprehensive risk measure incorporates benefits from dynamic hedging, the risk of hedge slippage and the potential costs of rebalancing such hedges.

Limited functionality currently is available in the KRM solution to model and simulate dynamic hedging strategies.



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