

# Mark to Future and Operational Risk

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Many factors are driving firms to examine, quantify and manage operational risk more effectively. Many hurdles remain along the path, including the lack of both data and commonly accepted measurement methodologies. As a result, the landscape of operational risk management is changing quickly, and measurement techniques must keep pace. A solution for measuring operational risk is presented within the Mark-to-Future framework. Simulation and an actuarial approach combine to enhance the extensible framework and make excellent use of scarce data. The Mark-to-Future framework is shown to provide a flexible, extensible, scalable solution that meets the operational risk manager's goals today, while allowing scope for innovation.

Operational risk managers have the responsibility to preserve shareholder value and meet regulatory requirements. In order to do so, they must achieve three key goals:

- Actively measure firm-level regulatory and economic operational risk
- Sustain an internally and externally transparent framework for managing and measuring risk
- Provide decision-support methodologies and tools for enterprise-wide operational risk management.

Before any of this is possible, operational risk must be defined. After much debate, operational risk has been defined for regulatory purposes in the international banking industry as “the risk of loss resulting from inadequate or failed internal processes, people, systems or external events.” (See Bank of International Settlements 2001a.) Many people extend the definition for non-regulatory purposes to include strategic or business risk, namely, the

risk involved in making a bad business decision and reputational risk.

Once defined, risk cannot be effectively managed without proper risk measures. Tools such as process mapping, control assessment, project management and risk assessment go a long way in identifying and controlling operational risk. However, it is impossible to determine the appropriateness of such risk-mitigating activities without proper pre- and post-enforcement measures of risk. Furthermore, since risk cannot be completely eliminated, risk measurement is key to effective risk management.

Transparency in any process, system or method promotes understanding. Given the strict qualitative requirements of the BIS II Capital Accord, and the variety of users who may benefit from the information, a transparent process is necessary in operational risk management. Understanding not only the amount of risk, but where it resides, what contributes to the risk, and the impact of mitigation strategies, is important to a risk manager. Different views of

risk are also informative, such as being able to report risk measures across business areas and geographic regions. Such quantitative decision-support tools are central to advanced operational risk management.

These challenges, while significant, are not unlike those faced by other sectors of the risk management industry. For example, market and credit risk present many of the same hurdles. Through the extensive work done in these areas, it has become clear that no single methodology can stand the test of time. Therefore, a framework accommodating several different methodologies is required.

This paper presents the case that Mark to Future is the best approach to operational risk measurement and, specifically, capital calculation. Simulation within the Mark-to-Future framework (see Dembo et al. 2000) provides several important benefits, including:

- flexibility in modelling and the ability to specify arbitrary probability distributions and relationships between them (In particular, independence of loss processes is not a necessary assumption.)
- efficiency in aggregating risk measures throughout a reporting hierarchy (e.g., an organization structure)
- the ability to attribute risks and derive not only a firm-wide capital, but also the marginal contributions of each constituent unit to the whole, thereby facilitating capital allocation
- consistency with existing approaches to market and credit risk calculations (Existing tried-and-tested tools can be used for calculations and, ultimately, can lead to easier integration of market, credit and operational risk.)
- the ability to present key concepts such as “scenarios,” in an intuitive and easy-to-understand manner, making them easy to explain to non-technical audiences
- efficiency in using available data, including the combination of internal and external loss data

- the ability to present a scalable solution where more complex models or hierarchical structures may be added easily.

The Mark-to-Future framework provides much more than simulation alone. It was developed only after the deficiencies of simulation for analysing market and credit risk came to light. While operational risk at the firm-wide level can be addressed largely by pure simulation, more sophisticated measures (e.g., marginal VaR) and complex aggregation structures are important to risk managers. Other important considerations include: the availability and well-documented aspects of the Mark-to-Future framework, and the ease of integration of market, credit and operational risk when all can be measured within a common framework.

This paper aims to elucidate the advantages listed above through a more detailed look at the role of simulation in operational risk management. First, there is a short description of the regulatory proposals on operational risk and how they relate to capital calculation. Then the problem of operational risk capital measurement and management is discussed in more detail, including a summary of available input data and expected outcomes or measures. The problem is illustrated with a simple hierarchy borrowed from regulatory definitions. Next, the simulation approach is described in the context of the Mark-to-Future framework. The simulation methodology for operational risk measurement is illustrated by an example. The article concludes with remarks and directions for future research. A description of loss measurement models and suitable statistical representations for operational data are provided in another paper in this issue (Reynolds and Syer 2002).

### The regulatory landscape

Since one of the key concerns of the operational risk manager is regulatory compliance, any risk measurement approach must meet regulatory requirements. The current regulatory requirements have been provided in a series of documents produced by the Basel Committee on Banking Supervision, a committee of the Bank for International Settlement (BIS). (See BIS 2001a,

2001b, 2001c and 2001d.) These are summarized in Reynolds (2002) in this issue. Specifically, the proposed new Basel Capital Accord, or BIS II, (BIS 2001b) identifies three methods for calculating regulatory capital for operational risk; each increasing in sophistication:

- The Basic Indicator Approach
- The Standardized Approach
- The Advanced Measurement Approach.

The Advanced Measurement Approach (AMA) allows for a range of methods based on banks' internal risk estimates. It includes the Internal Measurement Approach (IMA) and the Loss Distribution Approach (LDA), which were introduced in an earlier consultative document (BIS 2001a). In addition to these, a Scorecard Approach (SCA) was introduced, and the door was left open for other "best practices" approaches to be considered as time goes on.

BIS II proposes that if banks move from the Basic Indicator Approach, along the continuum towards AMA, they will be rewarded with a lower capital charge. Further, BIS II mandates that failure to comply will be addressed by a variety of supervisory actions, including increased oversight, senior management changes and the requirement of additional capital. Many, if not most, internationally active banks now have staff who are dedicated to the quantification of operational risk.

Many banks have indicated that they would prefer to use AMA, and LDA in particular, for regulatory reporting, because they intend to use it for internal purposes. This is a sign that these banks believe that LDA is more rigorous and more accurate than the simpler approaches. It also indicates a belief that LDA is feasible within the current business practices of their bank.

This paper is concerned with a simulation approach to operational risk capital, and the application of the framework to the quantification of operational risk. In regulatory terms, all the proposed AMAs could involve simulation:

- In the IMA the  $\gamma$  factor that relates

expected to unexpected losses has to be calibrated. Whether or not a bank adopts the IMA, it is natural to be curious about the corresponding value of  $\gamma$ . The results may be derived and tested using simulation.

- In the LDA, there is scope for direct application of simulation to the calculation of capital, in much the same way that market and credit risk capital is calculated.
- In the SCA, the results of the scorecard can be used to allocate the enterprise-wide capital, or to adjust a capital figure already calculated for each business unit. In either case, the initial calculation of the capital must be supported by the same data and methodologies as the LDA and, hence, simulation can play an important role.

In all three cases, annual loss distributions play a central role, and the regulators insist that the calculations must be underpinned by internal loss data collected over a number of years. This insistence, and the introduction of the AMA, are signs that the distinction between regulatory and economic capital is fading.

### Setting the stage

Before discussing the Mark-to-Future framework and identifying its value to operational risk measurement, some key concepts must be introduced. The following sections provide a discussion of available and applicable input data for simulation models and define terminology to be adopted in later discussion.

### Inputs

The first step in calculating concrete annual loss distributions is to determine and calibrate the most appropriate models; this requires a large amount of input data. Ultimately, the input data must also be used to test the appropriateness and accuracy of the model results. Fortunately, several different types of input data are available for these purposes. Each type of data varies in its quality, quantity, appropriateness and ease of collection. The input data types are summarized in

Table 1 where they are listed in decreasing order of the ease with which they can be collected.

Data description
Internal loss events
Indicators
Internal near-miss events
Issues (scenarios)
External consortium losses
External public domain losses
Detailed classifications of all of the above

**Table 1:** Summary of input data types listed in decreasing order of ease of collection

Internal loss event data are a list of monetary exposures and dates of events experienced by the firm. The regulatory proposals are very clear that these data form the basis of all capital calculations under the AMA. Under Pillar 2 (Supervision), the proposals also require that the data be collected and maintained in a robust, systematic way using well-defined and fully documented internal processes.

Indicators are a time series of internal or external numeric factors that might influence operational losses, and so can serve as predictors of operational risk. For example, if the volume of transactions increases while the number of staff and availability of new technology decreases, the number of losses per period would probably increase. Such intuitive correlations lead many to believe that numerical correlations between indicators and losses can assist in calibrating loss distributions. Indicators are seen as having predictive powers regarding either the frequency of loss events, or the size of the resulting loss. Whether the data bear this out has yet to be determined.

Indicators, both internal and external, also provide static data that are important in developing defensible scaling models. Firms change their business focus, grow, merge, shrink and operate in inflationary economies. All of these contribute to the need to scale the internal loss data to mark

them to the operational market of the firm. Both types of external data (public domain and consortium) may also need to be scaled before they can be applied rationally to the calibration of internal loss models. Although the need for scaling is widely accepted, no standards have yet emerged in the finance industry, and no methodology has been suggested by the regulators.

Near miss data are comprised of event dates and monetary exposures—sums that might have been lost, although an actual loss was not realized. Near misses have been mentioned in the regulatory proposals (BIS 2001a), and there are intimations that they might be used to augment internal loss data in the calibration of the frequency distributions. In any case, near miss data are useful in helping organizations to learn about the kinds of things that can go wrong, thus preventing similar mistakes from leading to losses in other parts of the organization.

Issues, often known as “scenarios on risks,” might consist of a set of estimated frequency and approximate monetary exposures of hypothetical events, such as from a risk self-assessment. Although often referred to as “scenarios” in the industry, this data is termed “issues” herein to avoid confusion with the “scenarios” used in the Mark-to-Future framework. Many organizations are collecting such data, and issues have been mentioned in the regulatory proposals. Issue data might be more useful as a high-level view of where the most important risks lie, than as a producer of accurate capital calculations. Nevertheless, such data play an important role in certain areas, such as new business endeavors, where there is a lack of other data. Issue data can also, potentially, augment the tails of loss distributions, but such methodologies have yet to be fully developed.

External public domain loss data are a set of dated monetary exposures representing events experienced by other firms, taken from the public domain. An example is the F1RST database from Zurich IC<sup>2</sup> (see IC<sup>2</sup> F1RST 2002). External loss data from a loss data consortium, such as the GOLD initiative of the British Bankers’ Association are similar in form, if not in execution.

Not all of the above data are available in any given situation; nor will all available data necessarily be used. The decision about which data to use in which way must be part of the risk management process. Different procedures may be applied in different situations; for instance, if the required output is regulatory capital, the procedure may be different than that for internal economic capital calculation. The existing BIS II proposals do not explicitly specify a procedure for making such decisions, except in the simpler approaches to capital calculation.

Classification of all of the above data into commonly understood and accepted reporting structures is essential. Such structures are used internally by banks for risk reporting and management purposes. External data often also have hierarchical risk categories, or generic organizational units. These might also be categories prescribed by regulators (BIS 2001b) or set by a governing body.

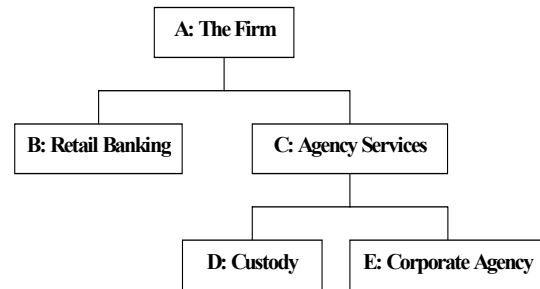
The next section formalizes the description of classifications and reporting structures by introducing the concepts of an operational unit, and an operational loss process.

## Operational units

The first goal of operational risk measurement can be stated as “the need to calculate consistent operational capital for each operational unit of the firm.” An operational unit is any entity (abstract or physical) for which a risk manager needs to assess operational risk and, possibly, allocate capital. Most businesses already break down into such units because of existing structures, such as reporting lines or geographical locations. Operational units are typically defined in a hierarchical fashion.

BIS II proposes two such hierarchies: one based on business lines, the other based on event type. Each node of a classification hierarchy can be interpreted as an operational unit. A hierarchy naturally translates into a portfolio-type view of the operational risk of an organization, breaking it up into categories and subcategories. A simple example hierarchy is shown in Figure 1. The operational units in the figure correspond to a small

subsection of the business line hierarchy from BIS II.



**Figure 1:** A simple hierarchy of operational units

Additional operational unit hierarchies include internal, as opposed to regulatory, organizational structure and risk categories, which may be desirable for reporting purposes. For instance, there are a number of different risk categorizations in common use, including so-called event-based and effect-based categorizations. Geographical or process-based categorizations are also commonly used. Organizations may need to report internal operational risk measures based on more than one of these hierarchies.

Hierarchies can also be combined with each other, as is the case in the IMA, where the business units each have a collection of risk classes for capital reporting purposes. Any pair of hierarchies can be similarly combined: the hierarchies can be viewed as the rows and columns in a table, or as two axes on a plane. Risk measurement takes place at all cells in the table (or points on the plane). This can be extended, in principle, to higher dimensions with more than two hierarchies. In practice, because of insufficient data, it will probably only be possible to obtain accurate measurements when at most two, very shallow, hierarchies are combined (as in the IMA).

## Operational loss processes

The constituents of an operational unit for risk-measurement purposes are operational loss processes. Each operational loss process can contribute hypothetical losses with a particular set of characteristics (e.g., impact, frequency) to the operational unit to which it belongs. For example, if an actuarial model is used, an operational loss

process is the combination of a frequency distribution and a severity distribution. Together, these two distributions provide a model for potential future losses.

It is often useful to be able to assign more than one operational loss process to an operational unit. For instance, if they correspond to actually distinct physical processes (e.g., manual and automatic settlement), then representing the two processes separately is more intuitive, and is likely to reflect reality more accurately.

Assumptions must be made to create a risk quantification for each operational unit by combining its constituent operational units and operational loss processes. The range of assumptions that can be made depends on the calculation methodology that is employed. Note that operational loss processes need not be independent of each other in a statistical (or any other) sense.

From this definition of an operational loss process, a distinction can be made between primary and aggregate operational units. A “primary operational unit” is an operational unit that is modelled by a single operational loss process that has no “descendants.” An “aggregate operational unit” is one that has several operational loss processes as “children.” Note that the aggregation methods used to combine operational units can also be used for operational loss processes, which allows the term “aggregate operational unit” to encompass all remaining possibilities. To see that this is the case, consider a hierarchy where operational unit X is modelled by two operational loss processes, y and z. By introducing a new level into the hierarchy, two “child units” of X, Y and Z, can be created, each containing a single operational loss process. So, the effect of having child units and multiple operational loss processes must be the same to preserve consistency. Operational units with one or more descendants, or modelled by more than one operational loss process, or having any combination of descendants and operational loss processes, can be treated in the same fashion.

### Codependence

Once a reporting hierarchy or classification scheme has been defined, many issues become

easier to articulate. For example, one serious concern is the interrelations between operational units. Codependences between operational units arise in at least two ways. They can arise “naturally” as a result of internal or external causes that affect distinct loss events. For instance, two loss events might be reported in geographically distinct locations, but have a common causative influence, such as an extreme market movement that creates stress and leads to human error. If the decision has been made to hold capital against such events separately in the two geographical locations, the calculation of the amount of capital to hold will be affected by the correlation between some of the events in each area.

Codependences also arise “artificially” if a single loss event has effects that are shared through the categorization of operational units. For example, if the financial impact of a single event is shared between two operational units, then that event is effectively split into two losses. But the two losses are not independent because they derive from a single underlying event, so there is an implied correlation. The capital held by the two operational units, and by operational units higher up the hierarchy, depends on this correlation.

Having examined possible data sources and formalized a language for classifying data, the problem of risk measurement is now more clearly defined. Based on this definition, the following section presents a simulation solution based on the Mark-to-Future (MtF) framework.

## Mark to future and operational risk

Operational risk can be seen as the risk of losing money as a result of an event or a chain of events. Many other kinds of risk have this event-driven character. In fact, event risk is a familiar and well-understood concept in a large sector of the financial industry: insurance. Adapting the experience of the insurance industry to operational risk is a matter of defining the relevant types of events.

Insurance companies underwrite the risk of their clients losing money owing to events that are defined in their policy documents. The key tool for an insurance company in understanding its

own risk is an actuarial loss model. The primary element of an actuarial model is to describe the annual loss, not as a single loss caused by a single event, but as the result of the aggregation of a number of loss events, each of a potentially different size. In other words, the distribution of total loss, rather than being estimated directly, is derived from the combination of frequency (number of losses) and severity (size of each loss) distributions.

Using actuarial assumptions as an underlying model, the Mark-to-Future framework can be adapted to operational risk measurement in a straightforward fashion. (For more information about the actuarial approach, see Reynolds and Syer 2002.)

### The Mark-to-Future framework

The purpose of Algorithmics' Mark-to-Future framework (Dembo et al. 2000) is to enable a range of simulation approaches to risk management problems. The framework is an abstraction of the process of scenario generation and the transformation of scenarios into financial results, together with the analysis of those results to produce risk measures. The application of Mark to Future to operational risk capital calculation hinges on the definition and modelling of basis instruments. The more straightforward approach is to define a basis instrument to be an operational loss process. A large degree of flexibility as to how they are modelled can be accommodated.

The Mark-to-Future framework is described as follows:

The MtF methodology for risk/reward assessment is summarized by the following six steps, each of which can be explicitly configured as an independent component of the overall process. The first three steps *build* the MtF Cube:

- Define the scenario paths and time steps.
- Define the basis instruments.
- Simulate the instruments over scenarios and time steps to generate a MtF Cube.

The next three steps *apply* the MtF Cube:

- Map the MtF Cube into portfolios to produce a portfolio MtF table.
- Aggregate across dimensions of the portfolio MtF table to produce risk/reward measures.
- Incorporate portfolio MtF tables into advanced applications.

Each step and its application to measuring operational risk is discussed in some detail in the following sections.

### Scenarios

As with any application of the MtF framework, the first step is both the most difficult and one of the most important. *Which* scenarios are used is a deciding factor in the level of every risk measure. In operational risk terms, the problem is even more fundamental than *how* to create appropriate scenarios. The question here is: What should be the basis of the scenarios? In other words, which "risk factors" should the scenarios cause to change in value?

Consider the simple case of a single operational loss process. The "scenario" in an actuarial model is the number of losses incurred during a specified period. (Note: This may be extended to multiple periods of various length within the framework.)

With this information, one could go on to price each of the losses incurred using the severity distribution.

Scenarios contain the number of losses incurred in each operational loss process. Many possibilities for generating these scenarios, some simple and many complex, exist. For example, if all operational loss processes are independent, then generating scenarios is straightforward, since one need only sample from the frequency distribution of each operational loss process. On the other hand, complex interrelations and correlations may exist between the operational loss processes. In such cases, multifactor models, or other more sophisticated tools may be used to emulate observed codependence. (For an overview of codependence

models, see Reynolds and Syer 2002, and for an example, see Powojowski et al. 2002, in this issue.)

### Basis instruments

The definition of a basis instrument is implicit in the definition of the scenario variable as the number of losses incurred in an operational loss process: a basis instrument is an operational loss process. Despite the simplicity of this statement, several factors influence the determination of the set of basis instruments. Chief among these are the definition of the hierarchy, the use of multiple operational loss processes to model a single operational unit, and the merging of two or more hierarchies.

The most straightforward application of the framework would be to determine a hierarchy of operational units, and assume that each “leaf” of the hierarchy is a primary operational unit. In this case, the leaves of the hierarchy become the basis instruments, since each is represented by exactly one operational loss process. However, by increasing the number of operational loss processes, a better model of the underlying business processes might be achieved.

Finally, when merging two hierarchies together, each combination of “leaf” units must be represented by its own operational loss process. For example, consider two hierarchies and their merged nodes. In the hierarchy from Figure 1, the firm is divided into Retail Banking and Agency Services. In the hierarchy from Figure 2, risks are divided into People Risks and Process Risks. Merging the two hierarchies creates four leaves: People Risks in Retail Banking, People Risks in Agency Services, Process Risks in Retail Banking and Process Risks in Agency Services. Any node on either hierarchy could be evaluated if the total annual loss for each of these four categories were known. In this simple case, only four leaves emerged. In fact, combining typical hierarchies at the second level leads to dozens of leaves—each of which must be modelled by at least one operational loss process.

Note that scenarios are typically created before the basis instruments are priced, hence the sce-

narios step precedes the basis instruments one in MtF. In operational risk, the set of basis instruments is important in determining which scenarios must be generated. This is not inconsistent with using MtF for operational risk. In market risk, a typical basis instrument is a zero coupon bond. In order to price such bonds under the scenarios, one must include the proper interest rates as scenario variables. Similarly, to model the operational loss processes properly, one must create scenarios on their frequency.

### Pricing losses

The pricing of instruments in the market risk setting has a direct analogy in operational risk terms. Given the number of losses incurred, as indicated in the scenario, the total price of the losses must be determined.

Consider a single period in which the scenario indicates  $n$  losses have been experienced in a particular operational loss process. In the simplest case, the severity of a loss (i.e., its size) is independent of the number of losses. So, the total loss is determined by sampling  $n$  times from the associated severity distribution and totalling the results.

Less straightforward pricing schemes are also possible. For example, the severity distribution itself might evolve as samples are drawn. Consider the case where an insurance contract with a deductible of  $X$  is held to cushion the bank from extraordinary losses. In this case, if the total of the previous draws is greater than  $X$ , all subsequent draws have severity zero. In a similar fashion, one might assume that after a loss greater than  $Y$ , the department is closed down, again resulting in any subsequent hypothetical losses having zero value.

As another example, the severity might depend on the frequency. For example, if more than  $K$  losses occur, the controls would be improved so that each subsequent loss must be sampled from a separate severity model.

The “price” of loss for each basis instrument (operational loss process) under each scenario is computed and placed into a Mark-to-Future table. In general, this structure also has a time dimension (one could assume a time line of loss

frequencies in the scenarios), and so the resulting structure is commonly referred to as a Mark-to-Future cube. (Take particular note of the dimensions of the cube: namely, the basis instrument  $\times$  scenario  $\times$  time.) The creation and usage of the MtF cube is the linchpin of the framework.

### Mapping to hierarchies

Once the MtF cube has been populated, determining the loss distribution for any operational unit is a matter of locating all of the basis instruments that comprise the operational unit and summing their values (under each scenario) to obtain a total loss. An aggregate operational unit needs to be decomposed into its descendants until the basis instrument level is reached. Only then can the total be properly calculated.

The result of these calculations is typically another MtF cube. In this case, the dimensions become: operational unit  $\times$  scenario  $\times$  time. It is especially important to note that the scenario and time dimensions remain unchanged. All that has happened in this step is the summation of basis instruments values to obtain operational unit total values.

### Computing risk measures

The goal of this entire process is to measure operational risk. (One additional step that is optional is outlined next.) To obtain the loss distribution for a particular operational unit at a particular time, fix the operational unit and time, and remove the slice of the cube along the scenario dimension. This produces a vector of values representing a discretization of the loss distribution.

Typical risk measures such as moments and confidence levels (VaR) can be easily computed by analysing the appropriate vector within the MtF cube. More sophisticated statistics, such as marginal VaR, can be calculated using weighted combinations of vectors.

### Using MtF tables

A further application of the MtF framework to risk analysis uses the MtF table as a tool in identifying risks. The MtF table is a particular slice of a

MtF cube. For example, fixing one dimension such as time, a table can be created showing the value of each operational unit under each scenario. Particularly risky scenarios can be identified by large losses.

Note also that scenarios need not be generated randomly. Stress scenarios can also be added to the simulation, and then examined individually for their potential impact using an MtF table.

### Benefits of Mark to Future

The Mark-to-Future framework was designed to enable a new generation of risk quantification and management software, and it has a number of key features that make it an excellent choice for market, credit and operational risk measurement and management purposes. For example,

1. It is efficient for dynamic portfolio measurements, and intra-day calculations such as “what-if” trades.
2. It allows multiple portfolios to be constructed from the same simulation results.
3. It is efficient for marginal risk calculation within a portfolio. For example, a position can be reset to zero and the risk statistics recalculated without repricing the instruments.
4. It enables the integration of market, credit and operational risk through the use of common risk factors.

For operational risk, the most important of these is probably #3, because it provides a natural method for allocating capital. Operational risk managers will also benefit from #2, because capital (and other risk measures) need to be reported in a number of portfolio (i.e., operational unit) hierarchies, such as business units, risk classes, geographical locations and process elements. There are enormous potential benefits from the integration of market, credit and operational risk quantification, so #4 is also very important. Having market, credit and operational risk quantified within the same framework, on the same platform, and using the same software architecture promote their eventual integration. The

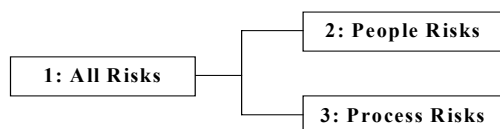
details of this integration are beyond the scope of this article, however.

The advantages of the simulation approach are both its simplicity, and its powerful ability to deal with a variety of frequency and severity distributions with complicated dependencies between loss events. The main advantage of the actuarial approach is its efficient use of scarce data.

### Example

To illustrate the application of Mark to Future to operational risk measurement, a simple example has been devised. The data used in the example are purely hypothetical. Since the example is intended as a proof of concept for the framework rather than as an insight into operational risk itself, the data values are immaterial.

Consider a very simple firm with an organizational structure as previously outlined in Figure 1. The firm's operational risk manager (ORM) wishes to measure annual capital using VaR(95%). Risk profiles for each part of the firm and for each of the two risk classes are required: People Risks and Process Risks. The breakdown into risk classes is shown in Figure 2. Note that each portfolio element in both hierarchies (A, B, C, D, E, 1, 2, 3) is an operational unit.



**Figure 2:** Risk categorization hierarchy

Capital for these risks is not necessarily regulated, but economic capital can be held by the firm as a buffer against them. An economic capital figure is also an efficient way of prioritizing risk control and mitigation actions. For example, action plans to control and mitigate unacceptable risks may be put into place based on such capital calculations.

To measure annual capital using VaR(95%), the ORM must derive a set of basis instruments composed of operational loss processes. To measure

people risk in any given part of the firm, it must be distinguishable from process risk in that part of the firm. This basic analysis leads to a set of initial basis instruments, shown against the hierarchies, in Figure 3 as items 2B, 2D, 2E, 3B, 3D and 3E. Reviewing the available data, the ORM might decide to use the results of a recent risk-profiling exercise. In this risk-profiling process, the business managers were asked to identify two issues (scenarios) for each type of risk: a typical and a worst case. The data collected during risk profiling is shown in Table 2.

For the purposes of this example, consider that each issue (scenario) is modelled separately. This results in two operational loss processes for each of the initial basis instruments in the table shown in Figure 3. In fact, the effect is to make each of the initial basis instruments (2B, 2D, 2E, 3B, 3D and 3E) an operational unit, and to identify two operational loss processes per operational unit.

To simplify the example, the same modelling assumptions are made for all operational loss processes of the same type. The frequency distribution is presumed to be Poisson for all operational loss processes (with mean shown as Expected Frequency in Table 2). The severity is presumed to be lognormal, with variance five times the mean, for all typical scenarios, and normal, with variance one-fifth of the mean, for all worst-case scenarios. The mean of the severity distribution for all scenarios is shown in the table as the Expected Loss. Note that these simple assumptions could be transformed to richer representations of reality by including more data in the analysis. One could also try different choices of frequency and severity distribution to test the results.

Assume that no correlations exist among the operational loss processes. The next step is to simulate the basis instruments (operational loss processes) and produce an MtF cube. Suppose that 100,000 scenarios are used. The dimensions of the cube are  $12 \times 1 \times 100,000$ . There are twelve operational loss processes, one time horizon (one year), and 100,000 scenarios.

Once an MtF cube is available, MtF tables can be trivially derived without resimulation. One MtF

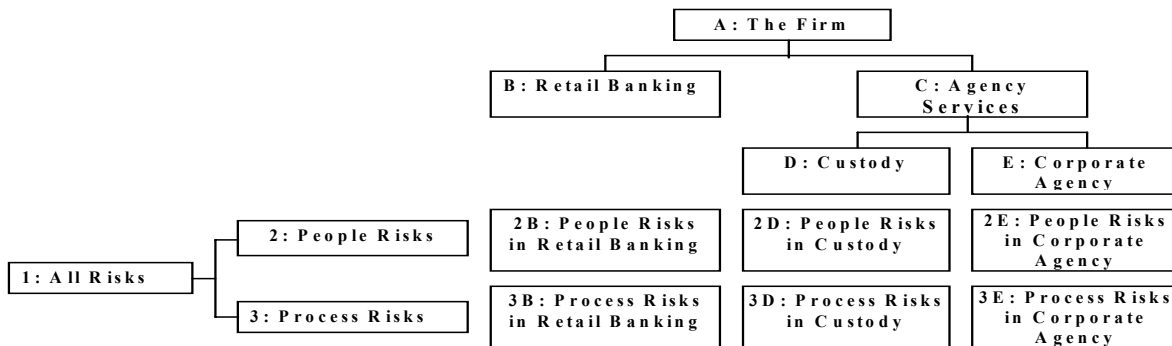


Figure 3: Identification of operational loss processes (basis instruments)

table relates to the organizational structure of the firm. Its dimensions are  $5 \times 1 \times 100,000$ . The time horizon and scenario dimensions remain constant, but the 12 basis instruments are aggregated along the hierarchy, leaving one plane of the table for each of the operational units shown in Figure 1. Another MtF table represents the risk class hierarchy. Aggregating by risk class, as per Figure 2, produces an MtF table of dimension  $3 \times 1 \times 100,000$ .

From these two derived MtF tables, summary statistics may be calculated using simple arithmetic on the rows and columns. Unless one requires reporting on People Risks in Corporate Agency, or other information at a similar level, the MtF cube itself may now be discarded. It is important to note that the two tables were produced from the same MtF cube without resimulating. This key feature of the Mark-to-Future framework drives many of the benefits derived from it.

Operational Unit LD	Business Line	Risk Class	Issue	Potential Loss	Expected Frequency (per year)
2B	Retail Banking	People	Typical	100K	1.00
			Worst Case	10M	0.01
2D	Custody	People	Typical	1M	0.10
			Worst Case	100M	0.01
2E	Corporate Agency	People	Typical	200K	5.00
			Worst Case	40M	0.01
3B	Retail Banking	Processes	Typical	2M	0.10
			Worst Case	200M	0.01
3D	Custody	Processes	Typical	100K	10.00
			Worst Case	30M	0.01
3E	Corporate Agency	Processes	Typical	800K	3.00
			Worst Case	500M	0.05

Table 2: Summary of issue data arising from a fictional risk-profiling exercise

Table 3 shows the VaR(95%) results for each operational unit in the organizational structure and each operational unit representing a risk class. As further examples of using the MtF cube, the mean and standard deviation of losses is also shown for each operational unit. Note that certain desirable properties are preserved: VaR is not additive along the aggregation hierarchy and, at the top of both hierarchies, the result is the same. The preservation of these important properties in the MtF framework is critical.

Unit	Mean	Standard deviation	VaR (95%)
A	32.99M	125.40M	633.27M
B	2.35M	22.70M	14.45M
C	30.65M	123.19M	631.56M
D	2.42M	13.87M	39.76M
E	28.23M	122.47M	631.38M
1	32.99M	125.40M	633.27M
2	2.76M	15.49M	51.08M
3	30.23M	124.49M	632.35M

**Table 3:** Summary statistics for each operational unit

The results clearly reflect the significant typical and worst-case scenarios submitted for Process Risks in Corporate Agency. Both scenarios for this operational loss process are larger than for any other operational loss process in the example. This leads to large VaR(95%) values for both Corporate Agency and Process Risks.

More complex risk measures may also be calculated by approximating the partial derivative of the firm-wide VaR with respect to the overall scale of the loss distribution at each operational unit. This is very efficient to calculate within the Mark-to-Future framework because it is a post-cube operation. In other words, it does not require a resimulation.

### Conclusions

The Mark-to-Future framework, originally conceived to facilitate the measurement of market

and credit risks, can be employed to support an Advanced Measurement Approach for operational risk capital calculation, and to achieve measure-influenced management of operational risks. The framework lives up to its name, providing a forward-looking logical structure for modeling, simulating, measuring and discussing operational risk that is consistent with other risk types. It is flexible enough to accommodate many different data sources, models and measures, while being time efficient by limiting resimulation requirements.

The modelling and quantification of operational risk is still a young discipline, and using the Mark-to-Future framework is a big step forward. The framework allows the measures and methods employed in measuring other types of risk to be applied to operational risk easily and effectively. Armed with such information, the deficiencies of these techniques in measuring operational risk may be determined and clearly articulated.

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