# Economic Capital
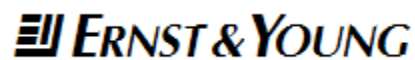# Correlation Matrices and Other Techniques – A Survey and Discussion

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**ERNST & YOUNG**

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# Executive Summary

In recent years, insurers have focused attention on the implementation of economic capital frameworks as part of risk management. Due to the diversity of products in an organization's portfolio, its overall risk profile is comprised of different risk categories. The general framework used by an organization for economic capital purposes is to determine its exposure to each risk independently, then aggregate them to produce an overall risk profile. As a result, an important aspect of the economic capital framework is the technique used to aggregate risks.

To gain insight into the approaches commonly used and impending developments, the Society of Actuaries Risk Management Research Team commissioned Ernst & Young to conduct a study of aggregation techniques employed by insurers. The study findings are based on a survey of a number of insurers with questions posed covering general economic capital methodologies and processes, risk aggregation techniques and respondent critiques of current methods.

Risk aggregation can be approached in two ways -- aggregation within a risk category and aggregation across risk categories. While the latter approach might be fairly intuitive, the former approach is less so. To illustrate aggregation within a category, consider the category of mortality risk. Mortality risk can be segregated into catastrophic risk, changes in mortality trend and fluctuations from the mean. The aggregation of these three components is an example of aggregation within a risk category.

The primary methods used to aggregate risk include integrated stochastic scenarios, correlation matrices and copulas. Results from the survey indicated distinct trends in current practices for both inter- and intra-risk aggregation:

- **Aggregation within Risk Categories (Intra-risk)**– The majority of survey respondents favored the use of integrated stochastic scenarios. For specific categories, this approach is used most often for market and credit risks as compared to other risks. The next most prevalent approach is that of correlation matrices.

- **Aggregation across Risk Categories (Inter-risk)** – Survey respondents most prevalently used integrated stochastic scenarios for aggregating market and credit risks. When aggregating market and credit risks with other risks, such as underwriting, results suggest they predominantly use correlation matrices.

In terms of use of correlation matrices, a key procedure is to calibrate the matrix parameters. A majority of respondents indicated that parameters were determined by approximation or professional judgment. The next most frequent response after approximations was the use of statistical techniques.

In regards to future developments, a significant number of survey respondents indicated that a more robust economic framework would employ integrated stochastic scenarios and copulas. As initial implementation of the frameworks have required simplified approaches for pragmatic reasons, respondents acknowledged that limitations in data and technology are currently inhibiting migration to more robust frameworks. While in the near term organizations may still use correlation matrices, there remains opportunity for further improvement and an increase in the accuracy of the economic capital results.

# 1.0 Introduction

As risk management evolves in the insurance industry, so do the techniques and methodologies used to quantify risk elements. The quantitative element of risk management that is the subject of this report is economic capital. Depending on the liabilities being valued, the risk elements that drive an organization's risk profile may differ. Given the diverse portfolio of risks at most organizations, there is a need to quantify and understand the contribution that each risk makes to the overall risk profile. This then drives the need to develop an aggregate risk profile for the organization.

As the practice of quantifying and aggregating risks continues to evolve, the techniques used are also evolving. To gain insight into the approaches commonly used and impending developments, the Society of Actuaries commissioned Ernst & Young to conduct a study of aggregation techniques currently employed by insurers. A survey of the current aggregation practices of a number of insurance companies was conducted in late 2007. The survey included questions covering general economic capital methodologies and processes, risk aggregation techniques and respondent critiques of their current methods.

This report is based on the survey findings. The first section describes the characteristics of the companies surveyed and subsequent sections provide insight into the risk aggregation techniques, use of correlation matrices and future plans of the respondents.

We would like to acknowledge the guidance and contributions of the Project Oversight Group. The group members were:

- Asutosh Chakrabarti
- Steven Craighead
- Ed Freeman
- David Hopewell
- Glenn Meyers
- Max Rudolph
- Fred Tavan
- Steven Siegel, SOA Research Actuary

# 2.0 Participant Characteristics

Before discussing the aggregation methods used in an economic capital framework, it is useful to describe the survey participants. Starting with a list of companies recommended by the Project Oversight Group, invitations were sent to the companies requesting their participation in the

study. Ultimately, thirteen of the invited companies agreed to respond to the survey. The participating companies, located in North America, represent a variety of businesses and risk management practices.

## 2.1    Geographic Influence

While the survey focused on the aggregation practices of North American companies, 38% of the participants are US subsidiaries of European-domiciled companies, 38% are based in the US and 23% are based in Canada (see Figure 1).  Home jurisdiction of the parent company is important because local regulatory influences may impact a company's economic capital methodology and practices.

*Figure 1.  Jurisdiction of Parent Company*

Canadian
23%

European
38%

US
38%
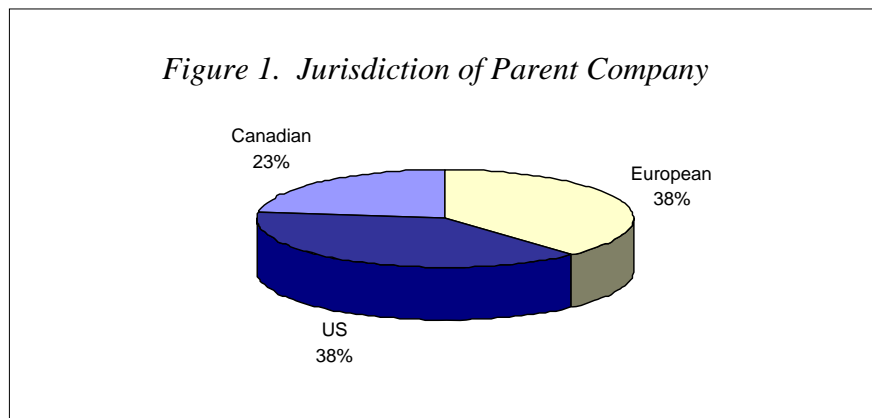
This report identifies factors in which geographic influences appear to have impacted decisions made by companies or where trends are seen in a specific region.

### 2.1.1   Industry Influence

The influence of a company's industry type is as important as its geographical location. Survey participants include life insurers, property/casualty insurers and financial institutions.  Some of the participating companies represent multiple industry segments.   As with geographic influences, the report identifies situations in which industry specific characteristics have influenced the techniques used.

### 2.1.2   Methodology Overview

Another differentiating factor is the economic capital methodology of the survey participants.  It is important to identify the underlying economic capital methodologies employed by the

participants because these methodologies are directly related to the risk aggregation techniques used.

Survey participants were asked to choose one of the following three methodologies as the one they used primarily: Fair Value method, Statutory Solvency method and the Cash Flow method. Participants were also given the option of responding with other methodologies, if not among the three method choices offered. Below is a brief description of these methodologies:

1. **Fair Value** – This method is based on an examination of the distribution of the economic surplus (defined as the fair value of assets less the fair value of liabilities) over a defined time horizon. This approach is the basis for the Solvency II capital framework, now in development in Europe, in which a one-year time horizon has been selected. The required capital is determined based on the tail values of the discounted distribution. (Methods used to calculate the required capital based on the tail values are discussed later in this report.) Emerging regulatory capital requirements in Europe and Canada are based on Fair Value.

2. **Statutory Solvency** – The Statutory Solvency method is similar to the Fair Value method in that it is balance sheet-based and determined by a distribution of the present value of projected surplus. However, it differs from the Fair Value method in that it is based on the statutory definition of surplus which is projected over the remaining life of the liabilities. Emerging principles-based regulatory developments in the US are Statutory Solvency based.

3. **Cash Flow** – Using the Cash Flow method, an amount required at the valuation date to fund liability outflows over their remaining life is determined. Like the other methods, economic capital is determined based on a distribution of results. The Cash Flow method differs from the other methods in that balance sheet amounts are not required. Note that this method is not currently associated with regulatory developments.

Survey results showed that 70% of the companies use a Fair Value based method (see Figure 2). Considering the geographic distribution of the participants, the dominance of the Fair Value methodology was not a surprise. For European and Canadian based organizations, it is not surprising that Fair Value is the dominant approach given that regulatory capital requirements in these jurisdictions are moving towards Fair Value frameworks. Of the companies domiciled in the United States, 50% identified Fair Value as their economic capital methodology. Discussions regarding the developments in GAAP (FAS 157/159) and the IFRS influence in the United States have encouraged and will likely continue to encourage interest in the Fair Value methodology.

As indicated above, the respondents who identified either the Statutory Surplus or Cash Flow approaches were primarily domiciled in the United States. Given that statutory regulatory

requirements are moving towards the Statutory Surplus based methodology, it is not a surprise to see this method used by US insurers.

In-depth discussion of trends and comparisons in economic capital methodologies is beyond the scope of this report; however, we recognize that the frameworks identified by the survey participants are important in interpreting the survey results.



*Figure 2. Primary Economic Capital Methodology*

Cash Flow 15%

Statutory Solvency 15%

Fair Value 70%
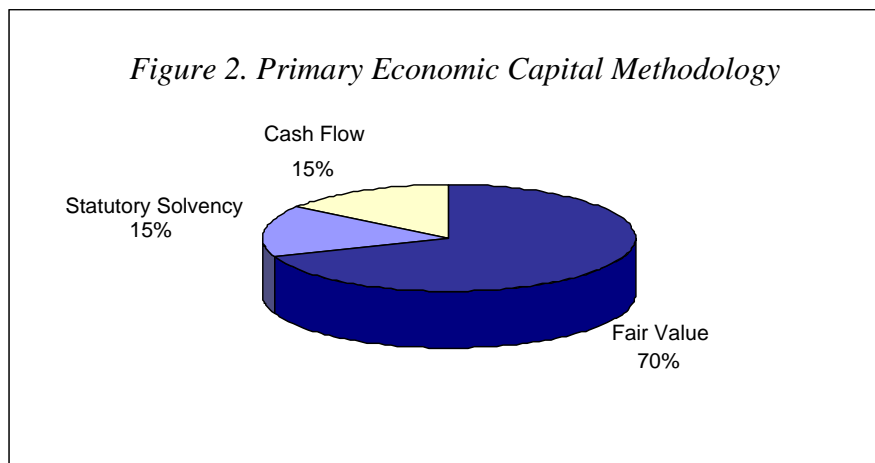
*See Question 1 in Appendix B*

## 2.1.3  Tail Exposure

While the underlying definition of solvency is identified in the methodologies described above, the quantification of economic capital is also dependent on the tail metric selected.  Common tail metrics used include Percentile ("VaR"), Standard Deviation, Conditional Tail Expectation ("CTE"), and Modified CTE.  The Percentile metric is usually associated with the Fair Value methodology while CTE and Modified CTE are used with the Statutory Solvency Method.  The following is a brief description of each:

- **Percentile (VaR)** – The value of a specified percentile is the tail exposure.

- **Standard Deviation** – The tail exposure is defined as a specified multiple of the standard deviation from the mean.

- **Conditional Tail Expectations (CTE)** – CTE is defined as the average of the (1-X %) percentile of the distribution.

- **Modified CTE** – This method is the same as CTE, but with results in the specified percentile capped at zero (i.e. all positive results are zero in the average calculation).

The majority (77%) of the companies surveyed selected the Percentile approach as the tail metric in their economic capital framework. The CTE and Modified CTE metrics were of secondary importance to over half (54%) of the respondents. Note that of the 13 companies surveyed, 5(38%) indicated the use of more than one tail metric.

It is worthwhile noting that the new regulatory frameworks emerging in Europe include the use of Percentile tail metrics, while North American frameworks have focused on CTE and Modified CTE techniques. Related to the following sections on aggregation of risks and the use of correlation matrices, it is also worth noting the impact that the tail metric has on the potential error in the calibration of approximation techniques.

### 2.1.4 Target Audience

Another element key in interpreting survey results is the target audience(s) for whom the economic capital metrics are being prepared. The survey asked participants to prioritize and rank three target audiences -- Rating Agencies, Internal Management and Regulators. All 13 survey respondents indicated Internal Management as their highest priority target audience (see Figure 3).

The evolution of capital requirements and metrics is not consistent across jurisdictions. European jurisdictions have recently made strides in the development and introduction of new accounting (IFRS) and capital (ICA, Swiss Solvency Test and Solvency II) requirements while the US and Canada are a step behind. As a result, the influence of regulators is expected to be greater for European companies compared with US and Canadian companies.

Interpretation of the participants' ranking of Rating Agencies and Regulators is not as clear cut as their ranking of Internal Management. US and Canadian companies rated Rating Agencies above Regulators, while European companies seemed indifferent between the two choices. In general, Rating Agencies were ranked second by 77% of the respondents (regardless of jurisdiction), while Regulators were ranked second by 42% of the respondents. Note that some companies identified more than one audience as their second priority.

*Figure 3. Summary of Target Audience for Economic Capital Reporting*

| Target Audience | Rank[1] | | |
|---|---|---|---|
| | *1* | *2* | *3* |
| Internal Management | 13 | 0 | 0 |
| Rating Agencies | 0 | 10 | 3 |
| Regulators | 0 | 5 | 7 |

*Results based on 13 responses. See Question 2 in Appendix B.
[1] 1 = highest priority; 3 = lowest priority

The importance of the target audience can be seen in the need to develop aggregation techniques to meet voids that may be left by industry standards. The use of regulatory standards is often seen in internal management reporting requirements. This leads to situations in which the needs of one audience are met with the information and techniques designed for another audience and purpose.

## 2.1.5   Granularity of Results

Survey participants were asked to identify the granularity of their economic capital models compared to the level at which the results are reported. All of the companies indicated that capital is calculated at the Business Unit or Product level (see Figure 4). All of the companies quantify capital elements at multiple levels of the organization. In reporting economic capital results, the majority of responses were at the Global and Corporate level of the organization.

*Figure 4.   Level that Capital is Modeled and Reported*

| Level | Model | Report |
|---|---|---|
| Business Unit/Product | 13 | 0 |
| Global/Corporate | 0 | 10 |
| Legal Entity/Geographic | 0 | 5 |

*Results based on 13 responses. See Question 3 in Appendix B.

While there were no surprises in the granularity of the modeling and reporting, the results clearly indicate the need to aggregate results across an organization. The tendency in current practice is to quantify results at a level lower than the reporting level.

Considering the difference in target audiences and the level of capital quantification, the need to organize and quantify results at multiple levels of an organization presents challenges. The challenges include the aggregation and allocation of diversification impact across levels of an organization. Two key questions emerge:
-- Where used, are correlation matrices calibrated at each level of granularity?
-- How do the aggregation techniques impact the results?

These issues will be addressed later in this report.

*2.1.6   Risks Quantified*

In addition to methodologies and target audiences, it is important to understand the risks that companies are quantifying. This is useful because the variety of risks quantified is directly related to the methods used to aggregate capital requirement results across risk categories.

Survey participants were asked to select which risk categories are currently taken into account in their capital requirement calculations. For the purpose of this report, market risk is defined to include interest and equity risks and exclude credit risk. All respondents indicated that market and credit risks are included in their current methodology. This result is not surprising given that market risk is one of the greatest risks facing insurance and banking organizations. The next most common risk selected was underwriting risk, which was identified by 71% of the respondents. Other common risks selected include reinsurance, operational, catastrophe and foreign exchange.

As described later in the report, risk aggregation approaches used within market risk categories often differ from the techniques used to aggregate risk across other risk categories.

# 3.0   Risk Aggregation

The report has described the variety of risks that companies include in their economic capital calculation(s). As the number of risk categories has increased, the challenge faced in aggregating these risks has also increased. The survey asked companies to summarize the aggregation techniques employed within each risk category as well as across risk categories. While the results of the survey on intra- risk versus inter-risk techniques are confusing, there are trends in the data worth reviewing. Section 3.1 begins with a discussion of techniques for aggregation within risk categories followed by Section 3.2 which discusses techniques for aggregation across risk categories. Section 3.3 concludes the risk aggregation discussion with a summary of participant satisfaction with their current aggregation techniques.

## 3.1   Aggregation within Risk Categories

This section discusses the techniques used to aggregate within risk categories.

At the outset, it should be noted that within a particular risk category, multiple risks can occur. For example, in examining the risk exposure due to mortality for a block of term life products, there is risk associated with normal fluctuations from the mean. In addition, there is risk associated with exposure to catastrophic events like an epidemic that dramatically increases mortality. Furthermore, another risk is the overall trend in mortality improvement. The

aggregation of risk exposure for these three risks to determine the total risk exposure due to mortality then illustrates an instance of aggregation within a risk category.

The survey asked participants to indicate the general method they use to aggregate risks within risk categories. Participants were also asked to indicate the method used for each risk category. Aggregation method categories included integrated stochastic scenarios, correlation matrix, copulas, other and none.



*Figure 5.   Aggregation Techniques within Risk Categories*
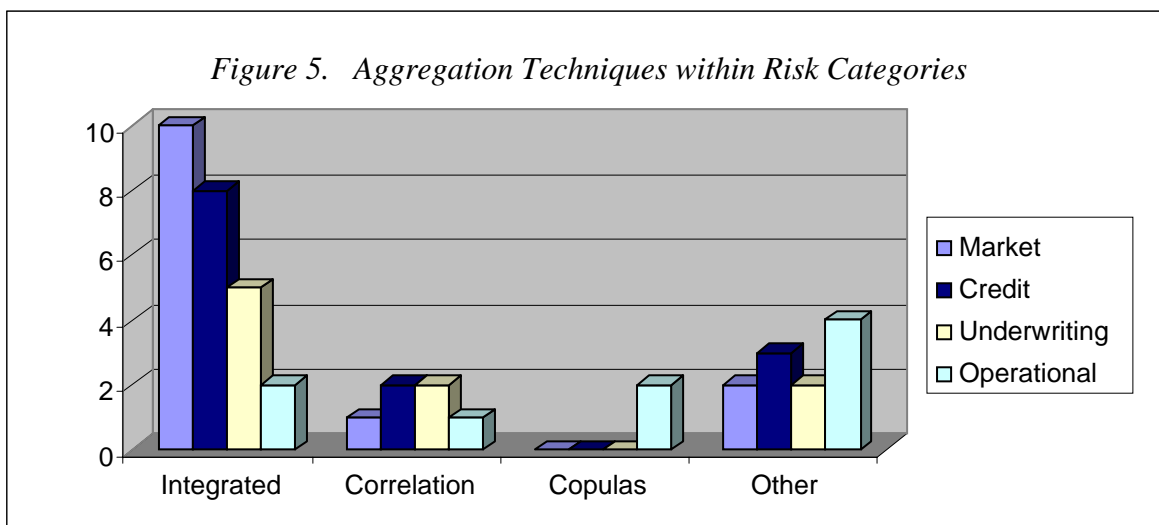
*Results based on 13 responses. See Question 7 in Appendix B.

In general, respondents overwhelmingly favored the use of integrated stochastic scenarios (see Figure 5). Eleven of the 13 respondents indicated that they use integrated stochastic scenarios in at least one risk category. Integrated stochastic scenarios are used most often for market and credit risks compared to other risks.

The next most prevalent method was correlation matrices with four of the 13 survey participants indicating its use.

Two of the survey respondents indicated the use of an "Other" technique. While these participants did not indicate what the other technique was, it is probable that shock/stress events are used.

In summary, it appears that the integrated stochastic scenarios method is the preferred approach for aggregation within risk categories. Outside market and credit risks, many of the intra-risk aggregations were not identified by most participants. Proceeding to aggregation across risks categories in Section 3.2, the use of correlation matrices becomes more prevalent.

## 3.2    Aggregation across Risk Categories

When determining the required capital for an entire organization, the aggregation across risk categories presents a challenge.  While theoretically appealing, the application of integrated scenarios has limited use when aggregating all of the risks of an organization.  Industry practice lies somewhere in the middle of the spectrum where a combination of integrated stochastic scenarios, correlation matrices and copulas are used.  Companies use integrated stochastic scenarios that combine a subset of the risk categories.  The subset is then aggregated with the other risk categories using techniques such as correlation matrices or copulas.



*Figure 6.  Aggregation Techniques across Risk Categories*
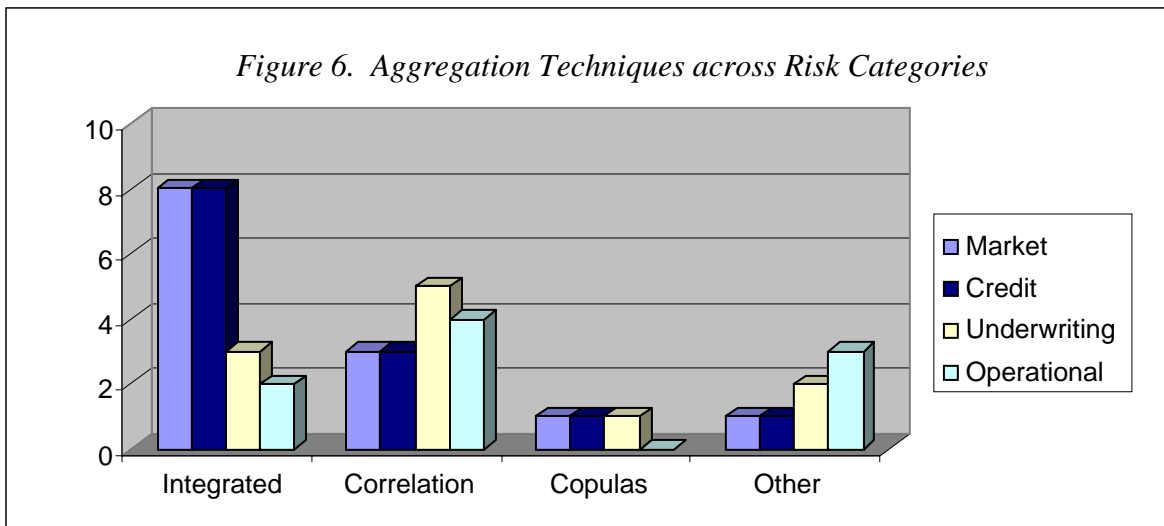
*Results based on 13 responses. See Question 8 in Appendix B.

Survey results indicate that the most popular method used for market risk is integrated stochastic scenarios (see Figure 6).    Eight of the 13 respondents indicated they use integrated stochastic scenarios for interest rate and equity risk.  The correlation matrices method is the most frequently used non-integrated stochastic technique, which suggests that if market risk is aggregated with non-market risks, correlation matrices are most likely used for the aggregation.

Only one respondent indicated it uses copulas exclusively across all risk categories.  Another respondent noted its desire to employ the copulas method in the future.

The aggregation of risks across an organization presents several levels of complexity.  First, there are products and business units in which the risks are primarily concentrated in a single risk category.  An example would be term insurance in which the majority of the risk is concentrated on mortality risk.  Alternatively, there are situations where multiple risk categories are present at product and business unit levels.  Next is the challenge of combining all of the products and business units in an organization.  For a diverse organization, the challenge of implementing an integrated scenario approach leads to the need for approximation techniques.

Regardless of the aggregation technique used, companies need to calibrate the interaction of risk categories. As the number of risks increase, this exercise becomes exponentially more difficult. The need to communicate results to multiple audiences is another complicating factor in the aggregation effort.

## 3.3 Opinion of Current Approach

In general, survey participants were very satisfied or moderately satisfied with their current aggregation techniques (see Figure 7). (Only one respondent indicated dissatisfaction.) This result is not a surprise given most organizations have only recently implemented an economic capital framework. However, the satisfaction expressed with current techniques is probably biased, to a certain extent, because those completing the survey were the owners of the economic capital process and models within their organizations. Hence, they have had personal involvement in directing the process and the option of revising it to their satisfaction. Only two respondents suggested they were reviewing other options. While respondents were aware of the limitations of current techniques, the satisfaction expressed points to the general concern of balancing practicality and limitations.



*Figure 7. Satisfaction Level*
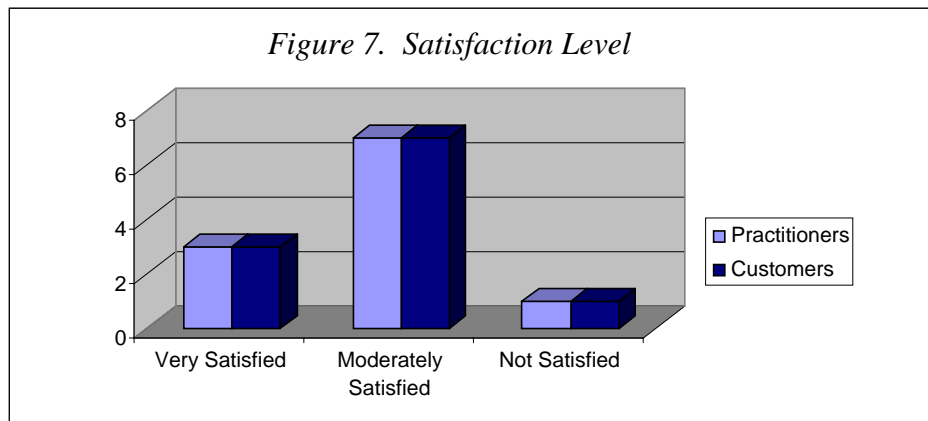
*Results based on 13 responses. See Question 14 in Appendix B.

Survey participants were asked to indicate the satisfaction of their economic capital customers on the current approaches used. Consistent with their own responses on the techniques currently used, participants indicated their customers to be generally satisfied. In addition, respondents were asked whether their customers were aware of the limitations with the current techniques. The results indicate that participants believe their customers are moderately aware of the limitations.

Ultimately, respondents said they would prefer to move towards a framework which would include the use of integrated stochastic techniques and copulas. While this would be a more

robust framework than what is currently employed, they recognize the need to initially implement their economic capital frameworks using simpler techniques. As companies move past initial implementation, it is expected they will adjust their modeling capabilities to support an integrated scenario framework.

# 4.0   Using Correlation Matrices

As discussed in the prior section, the use of correlation matrices is a common practice in the insurance industry, particularly for aggregating results across risks. This section discusses the techniques used in the parameterization and implementation of correlation matrices.

A key procedure in using correlation matrices is calibrating the matrix parameters. Numerous approaches can be used to calibrate or set correlation parameters. The approach choices offered in the survey include:

- **Statistical Techniques** – where distributions and statistical parameters are used to approximate the relationship between multiple risks.

- **Robust Modeling** – where the interaction of risks in a modeled environment is analyzed.

- **Approximations** – which  include using professional or expert judgment.

Respondents were also given the opportunity to describe other approaches.

A significant majority of survey participants use statistical techniques and approximations (see Figure 8) – specifically, using statistical techniques for the market and credit assumptions and approximation techniques for calibrating the other risks.



*Figure 8.  Calibration Approach*
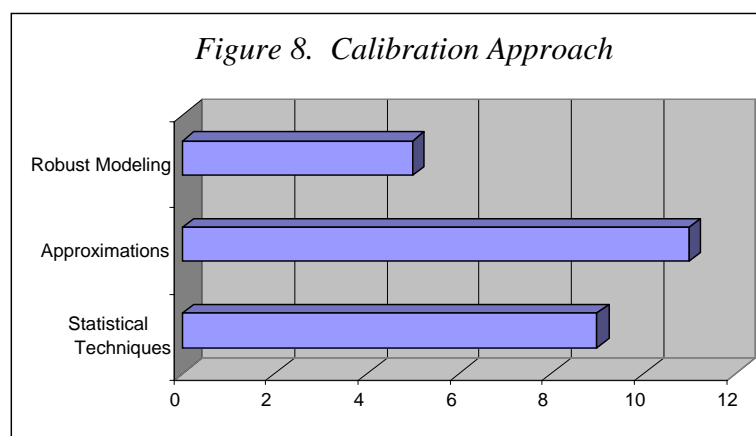
*Results based on 13 responses. See Question 9 in Appendix B.

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Overall, it appears the insurance industry relies on professional insight and approximate relationships for populating the correlation matrix. When assessing tail events, this is likely to be reasonably accurate for many of the risk assumptions. It is useful to note the difference between calibrating tail events for the risks versus tail events for the products exposed to those risks. This difference is due to the fact that the risk profile of products mapped against the array of risks does not always result in the same risk profile as in aggregate. For instance, the correlation between mortality and equity risk may be assumed to be zero for the general population, but may exhibit a positive correlation when correlating a specific product such as variable annuities with guaranteed minimum death benefits.

The majority of survey participants indicated that they calibrate the correlation parameters annually (see Figure 9). Some of the survey participants indicated that the frequency of calibration often differs by risk category.

*Figure 9.  Calibration Frequency*

| Frequency of Calibration | Respondents |
| --- | :---: |
| Quarterly | 2 |
| Annually | 7 |
| Other | 4 |

*Results based on 13 responses. See Question 10 in Appendix B.

Of the "Other" responses, one company indicated it calibrates every two to three years while the other three respondents indicated they calibrate either quarterly or annually

The following are questions to consider in the process of calibrating the matrix:

- Is the tail exposure to a risk a single shock event?  Or is the risk exposure optimized under an alternative scenario?  This could be the issue when considering secondary benefits offered under variable annuity contracts.

- What about the timing of an event?  Consider increased deaths on the same variable annuity contract.  The largest exposure may be deaths after a turn in the market.

- How do products interact across risks?  When products do not share the same risk profile, the diversification effect may not be easy to approximate.

In many cases, the diversification impact is one of the largest risk elements. When considering the size of the correlation effect on the final capital metric, it is important to consider all of the elements that can impact the correlation assumptions.

Another consideration is the changes in correlation or risks across the risk distribution. The correlation matrix may be different when calculating the value at one point on the distribution versus another point. One of the companies identified this issue as a current limitation of its correlation approach.

The following are three points to consider related to calibrating the matrix:

- The tail risk exposure for an organization is not the tail event of each risk or each product. How does the mix of business or business characteristics impact the correlation or risks?

- The correlation assumptions should be calibrated with the tail metric in mind. The tail metric includes the point in the tail as well as the quantification technique (VAR versus CTE).

- The hypersensitivity of some risks may not be considered when using correlation matrices. In other words, the sum of two risk events can result in a risk that is greater than the two events alone.

When asked what information was missing from their current approach, one company indicated that it would like "to better understand tail correlation or even to determine whether it is a real effect."

Participants were asked whether they use different correlation assumptions when considering differences in the audience, metric or conditions. The majority of the respondents (77%) indicated that differing assumptions were not used in differing situations (see Figure 10).



*Figure 10. Static vs. Varying Correlation Assumption*

Varying Correlation
Assumptions
23%

Static Correlation
Assumptions
77%
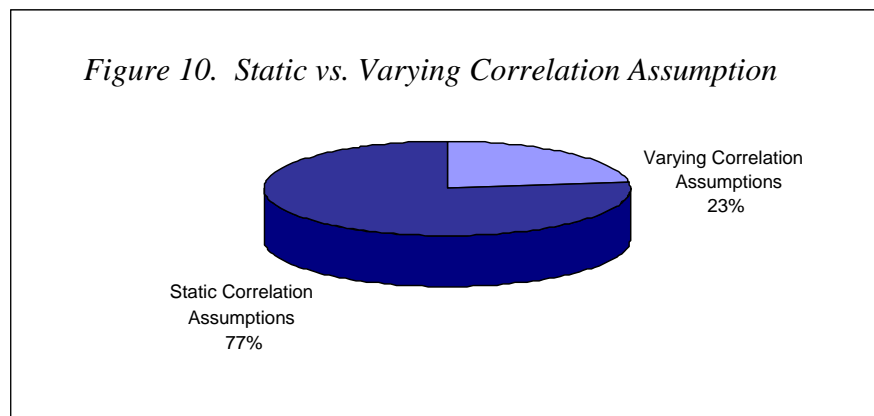
*Results based on 13 responses. See Question 12 in Appendix B.

In a separate question, 85% of the survey participants indicated that their aggregation technique permits "what if" capabilities, including a change in the mix of business. While the ability to

quantify the change in capital is an important feature, the static correlation assumptions could result in misleading analysis.

A key input into the process of calibrating the correlation matrices is actual data. When survey participants were questioned about the limitations in their current aggregation techniques, the primary response was difficulty in calibrating the correlation assumptions due to limited data. When asked about the data collected to support their current approach, participants referenced the collection of market data. This is consistent with earlier observations regarding the overwhelming focus on market risks.

## 4.1    Correlation Strength

After focusing on the techniques used to aggregate risks in an economic capital framework, survey participants were then asked to gauge the correlation strength between key risks. In an effort to simplify the data collection, the correlation strength was divided into five categories, as shown in Figure 11.

*Figure 11.  Correlation Strength by Category*

| Category | Correlation |
|----------|-------------|
| Strong Negative | -1.00 to -0.51 |
| Weak Negative | -0.50 to -0.01 |
| Zero | 0.00 |
| Weak Positive | 0.01 to 0.50 |
| Strong Positive | 0.51 to 1.00 |

*See Question 13 in Appendix B.*

From the responses, a summary of which is found in Appendix C, "Correlation Strength," there are several observations:

- The strongest correlations were noted between the market and credit risks.

- The market and credit risks also appear to have a strong correlation with the counterparty risk.

- The mortality and morbidity risks have zero correlation with all of the other risks, with the exception of operational risk.

- Foreign exchange risk has a strong correlation with reinsurance risk. This is likely due to the recent trend in offshore reinsurance.

The heat chart found, in Appendix C, illustrates the number of responses by category. It does not identify the frequency of response. In an effort to avoid outlier influence, only the risks that received responses from at least half of the survey participants are included.

# 5.0  Future Plans

Throughout this report, current practices and trends in the use of aggregation techniques have been identified and, more specifically, the use of correlation matrices. As economic capital frameworks evolve, the techniques used to aggregate risks will also likely improve. When asked, 85% of the survey participants indicated that they do not plan to change their aggregation approach. Only two companies said they plan to change their existing approach.

However, when asked how they would aggregate risks if data and technology limitations were eliminated, six of the companies (46%) indicated the desire to move to integrated scenarios (see Figure 12). When asked what is limiting their ability to move to a more robust solution, the availability of data and technology was most commonly identified.

*Figure 12.  Summary of Limitations*

| Limitation | Respondents |
|------------|:-----------:|
| Data | 6 |
| Technology | 5 |
| Resources | 3 |

*See Question 15 in Appendix B*

As economic capital frameworks evolve, companies' dependence on their results is increasing. As a result, the ability to ensure that the necessary processes and controls are in place will increase in importance. The majority of those surveyed indicated that they are currently using spreadsheets to correlate and collect data (see Figure 13). In light of this state of practice, it appears that a transition to a controlled "production" environment could be beneficial for the future.

*Figure 13.  Software for Data Collection and Correlation*
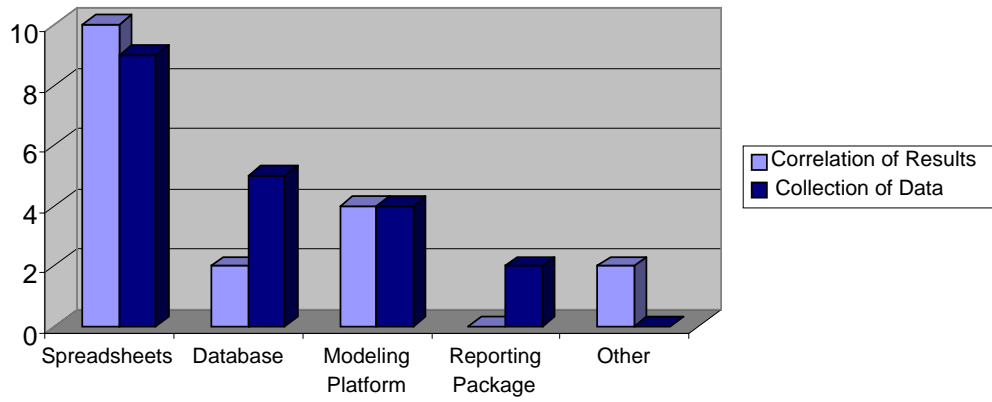
*See Question 4 in Appendix B.*

# 6.0   Conclusion

Economic Capital is a relatively new framework in the insurance industry.  The time and effort needed to implement an economic capital framework has been a significant hurdle for the industry. In a pragmatic effort to gain momentum, companies are using approximation techniques, as necessary. As with any evolution, the search for more efficiency and accuracy will drive the future evolution of economic capital techniques and procedures.

At the forefront of these more advanced techniques, use of correlation matrices in the aggregation of risk elements is likely to become even more widespread.  As shown by the survey results, the use of correlation matrices is apparently the norm in the insurance industry. Assessing the current use of correlation matrices, it is evident that there are opportunities to improve aggregation techniques.  The use of static correlation assumptions that are derived using limited data and professional judgment lags the robust models and the needs of informed, multiple users.

There is evidence that integrated stochastic solutions may replace or limit the use of correlation matrices in the future.  In the meantime, there are opportunities to improve the parameterization and use of correlation matrices.  On a final note, actuaries at insurance companies will find it beneficial to understand the limitations of their economic capital frameworks and work to improve the accuracy of their results.

# Appendix A – List of Participants

Aegon
Allianz
Allstate
Bank of America
The Hartford
ING
Manulife
MARC
MetLife
Nationwide
RBC
Sun Life
Swiss Re

Special thanks to all of the above participants for their time and effort in completing the survey.

# Appendix B – Correlation Matrices and Other Techniques Survey

## Background Information (Questions 1-6)

1) What is the primary methodology used to quantify capital requirements? *(select one)*

   a. Fair Value/Market Value – Assets sufficient to fund market liquidation of the assets and liabilities over a specified time horizon. (Solvency II approach)  ☐

   b. Statutory Solvency – Assets sufficient to ensure statutory balance sheet solvency over the life of the liabilities. (C3 Phase II approach)  ☐

   c. Cash Flow – Assets sufficient to fund the liability cash flows over the life of the liabilities.  ☐

   d. Other (please describe) _____  ☐

2) Who is/are the target audience(s) of your Economic Capital Reporting?
   Rank the following (1 = highest priority; 3 = lowest priority)
   *(Please select one ranking for each choice)*

| | Rank | | |
|---|---|---|---|
| *1* | *2* | *3* | *N/A* |

|  | 1 | 2 | 3 | N/A |
|---|---|---|---|---|
| a. Rating Agencies | ☐ | ☐ | ☐ | ☐ |
| b. Internal Management | ☐ | ☐ | ☐ | ☐ |
| c. Regulators | ☐ | ☐ | ☐ | ☐ |

3) At what level(s) do you model and report capital requirements?
   *(Choose all that apply)*

| Level | Model | Report |
|---|---|---|
| a. Corporate | ☐ | ☐ |
| b. Global | ☐ | ☐ |
| c. Legal Entity | ☐ | ☐ |
| d. Business Unit | ☐ | ☐ |
| e. Product | ☐ | ☐ |
| f. Geographic | ☐ | ☐ |

4) What technologies do you use to perform the correlation calculation and data collection?

| Technology | Correlation | Collection of Data |
|---|---|---|
| a. Spreadsheets | ☐ | ☐ |
| b. Database (e.g., MS Access, Oracle, SQL Server) | ☐ | ☐ |
| c. Modeling Platform (e.g., ALFA, MoSes, Prophet) | ☐ | ☐ |
| d. Reporting Package (e.g., Cognos, Business Objects, Hyperion) | ☐ | ☐ |
| e. Other | ☐ | ☐ |

If "Other" is selected please describe: _____

5) What approach(es) is/are used to quantify the tail exposure?
*(select all that apply)*

**Approach**

| | |
|---|---|
| a. Percentile (VAR) | ☐ |
| b. Standard Deviation Multiple | ☐ |
| c. Conditional Tail Expectation (CTE) | ☐ |
| d. Modified Conditional Tail Expectation (Modified CTE) | ☐ |
| e. Other | ☐ |

If "Other" is selected please describe: _____

6) What risks are currently quantified?
*(select all that apply)*

**Risk**

| | | |
|---|---|---|
| a. | Percentile (VAR) | ☐ |
| b. | Equity | ☐ |
| c. | Interest Rate | ☐ |
| d. | Credit | ☐ |
| e. | Mortality | ☐ |
| f. | Morbidity | ☐ |
| g. | Reinsurance | ☐ |
| h. | Foreign Exchange | ☐ |
| i. | Operational | ☐ |
| j. | Expense | ☐ |
| k. | Policyholder Behavior | ☐ |
| l. | Catastrophe | ☐ |
| m. | Non-Catastrophe | ☐ |
| n. | Other | ☐ |

If "Other" is selected please describe: _____

# Current Approach (Questions 7-13)

7) How are risks aggregated within a risk category (e.g., mortality risk elements include trend, volatility, underwriting and catastrophe)? Indicate which risks are aggregated for each aggregation method.

| Risk | Integrated Stochastic Scenarios | Correlation Matrix | Risk Distribution Aggregation (Copulas) | Other Approach | No Aggregation Used |
|---|---|---|---|---|---|
| Equity | ☐ | ☐ | ☐ | ☐ | ☐ |
| Interest Rate | ☐ | ☐ | ☐ | ☐ | ☐ |
| Credit | ☐ | ☐ | ☐ | ☐ | ☐ |
| Mortality | ☐ | ☐ | ☐ | ☐ | ☐ |
| Morbidity | ☐ | ☐ | ☐ | ☐ | ☐ |
| Reinsurance | ☐ | ☐ | ☐ | ☐ | ☐ |
| Foreign Exchange | ☐ | ☐ | ☐ | ☐ | ☐ |
| Operational | ☐ | ☐ | ☐ | ☐ | ☐ |
| Expense | ☐ | ☐ | ☐ | ☐ | ☐ |
| Policyholder Behavior | ☐ | ☐ | ☐ | ☐ | ☐ |
| Catastrophe | ☐ | ☐ | ☐ | ☐ | ☐ |
| Non-Catastrophe | ☐ | ☐ | ☐ | ☐ | ☐ |
| Other | ☐ | ☐ | ☐ | ☐ | ☐ |
| Total/Aggregate | ☐ | ☐ | ☐ | ☐ | ☐ |

If "Other" is selected please describe: _____

8) How is each risk category aggregated across the organization?

| Risk | Aggregation Methods | | | | |
| | Integrated Stochastic Scenarios | Correlation Matrix | Risk Distribution Aggregation (Copulas) | Other Approach | No Aggregation Used |
|---|---|---|---|---|---|
| Equity | ☐ | ☐ | ☐ | ☐ | ☐ |
| Interest Rate | ☐ | ☐ | ☐ | ☐ | ☐ |
| Credit | ☐ | ☐ | ☐ | ☐ | ☐ |
| Mortality | ☐ | ☐ | ☐ | ☐ | ☐ |
| Morbidity | ☐ | ☐ | ☐ | ☐ | ☐ |
| Reinsurance | ☐ | ☐ | ☐ | ☐ | ☐ |
| Foreign Exchange | ☐ | ☐ | ☐ | ☐ | ☐ |
| Operational | ☐ | ☐ | ☐ | ☐ | ☐ |
| Expense | ☐ | ☐ | ☐ | ☐ | ☐ |
| Policyholder Behavior | ☐ | ☐ | ☐ | ☐ | ☐ |
| Catastrophe | ☐ | ☐ | ☐ | ☐ | ☐ |
| Non-Catastrophe | ☐ | ☐ | ☐ | ☐ | ☐ |
| Other | ☐ | ☐ | ☐ | ☐ | ☐ |
| Total/Aggregate | ☐ | ☐ | ☐ | ☐ | ☐ |

If "Other" is selected please describe: _____

9) How do you calibrate the correlations used to aggregate results? *(check as many as may apply)*

a. Statistical techniques        ☐
b. Robust modeling               ☐
c. Approximations                ☐
d. Other                         ☐

If "Other" is selected please describe: _____ _____

10) How often do you recalculate correlation values? *(select or use "other" to describe)*

a. Quarterly                     ☐
b. Annually                      ☐
c. Never                         ☐
d. Other                         ☐

If "Other" is selected please describe: _____ _____

11) Does your technique permit "what if" analysis, including change in mix of business?

a. Yes                           ☐

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b.   No ☐

12) Are different correlation matrices used based on other factors such as environment, point on the distribution, audience?

a.   Yes ☐
b.   No ☐

13) For those correlation matrices currently in place, what is the relative value associated as the correlation between the elements shown in the table below?

Indicate the relative value as strong negative (SN) (-1 to -0.51), weak negative (WN) (-0.5 to -0.01), zero (Z), weak positive (WP) (0.01 to 0.5) & strong positive (SP) (0.51 to 1).

| Risk | Equity | Interest | Credit | Mort | Morb | Reins | FX | Ops | Exp | PH |
|---|---|---|---|---|---|---|---|---|---|---|
| | SN WN Z WP SP | SN WN Z WP SP | SN WN Z WP SP | SN WN Z WP SP | SN WN Z WP SP | SN WN Z WP SP | SN WN Z WP SP | SN WN Z WP SP | SN WN Z WP SP | SN WN Z WP SP |
| Interest Rate | ☐ ☐ ☐ ☐ | | | | | | | | | |
| Credit | ☐ ☐ ☐ ☐ ☐ | ☐ ☐ ☐ ☐ | | | | | | | | |
| Mortality | ☐ ☐ ☐ ☐ ☐ | ☐ ☐ ☐ ☐ ☐ | ☐ ☐ ☐ ☐ | | | | | | | |
| Morbidity | ☐ ☐ ☐ ☐ ☐ | ☐ ☐ ☐ ☐ ☐ | ☐ ☐ ☐ ☐ ☐ | ☐ ☐ ☐ ☐ | | | | | | |
| Counterparty (Reinsurance, Derivative) | ☐ ☐ ☐ ☐ ☐ | ☐ ☐ ☐ ☐ ☐ | ☐ ☐ ☐ ☐ ☐ | ☐ ☐ ☐ ☐ ☐ | ☐ ☐ ☐ ☐ ☐ | | | | | |
| Foreign Exchange | ☐ ☐ ☐ ☐ ☐ | ☐ ☐ ☐ ☐ ☐ | ☐ ☐ ☐ ☐ ☐ | ☐ ☐ ☐ ☐ ☐ | ☐ ☐ ☐ ☐ ☐ | ☐ ☐ ☐ ☐ | | | | |
| Operational | ☐ ☐ ☐ ☐ | ☐ ☐ ☐ ☐ ☐ | ☐ ☐ ☐ ☐ ☐ | ☐ ☐ ☐ ☐ ☐ | ☐ ☐ ☐ ☐ ☐ | ☐ ☐ ☐ ☐ ☐ | ☐ ☐ ☐ ☐ | | | |
| Expense | ☐ ☐ ☐ ☐ | ☐ ☐ ☐ ☐ ☐ | ☐ ☐ ☐ ☐ ☐ | ☐ ☐ ☐ ☐ ☐ | ☐ ☐ ☐ ☐ ☐ | ☐ ☐ ☐ ☐ ☐ | ☐ ☐ ☐ ☐ ☐ | ☐ ☐ ☐ ☐ | | |
| Policyholder Behavior | ☐ ☐ ☐ ☐ ☐ | ☐ ☐ ☐ ☐ ☐ | ☐ ☐ ☐ ☐ ☐ | ☐ ☐ ☐ ☐ ☐ | ☐ ☐ ☐ ☐ ☐ | ☐ ☐ ☐ ☐ ☐ | ☐ ☐ ☐ ☐ ☐ | ☐ ☐ ☐ ☐ | ☐ ☐ ☐ ☐ | |
| Other (as indicated in Question 6) | ☐ ☐ ☐ ☐ ☐ | ☐ ☐ ☐ ☐ ☐ | ☐ ☐ ☐ ☐ ☐ | ☐ ☐ ☐ ☐ ☐ | ☐ ☐ ☐ ☐ ☐ | ☐ ☐ ☐ ☐ ☐ | ☐ ☐ ☐ ☐ ☐ | ☐ ☐ ☐ ☐ | ☐ ☐ ☐ ☐ | ☐ ☐ ☐ ☐ |

## Critique of Current Approach (Questions 14-19)

14) How satisfied are you with your current aggregation approach(es)?

15) What are the current limitations, if any?

16) How well do you feel you understand the implications/limitations of your current approach(es)?

17) How satisfied are your customers (i.e. management, rating agencies) with your current approach(es)?

18) How well do your customers understand your current approach(es) and/or the limitations of it?

19) What data do you collect in order to maintain the current approach(es)?  Ideally, what data would you like to be able to collect?

## Future Plans (Questions 20-23)

20) Are there any plans to change the aggregation approach(es)?

   a.  Yes    □
   b.  No     □

21) If so what changes do you plan to make?

22) Assuming no data, technology or other limitations, how would you aggregate?

23) Is there anything that prevents you from moving to a more robust solution (e.g., data, time, resources technology)?

24) What information/questions did we not ask that you feel would be beneficial to our survey?

# Appendix C – Correlation Strength

| Risk | Equity SN WN Z WP SP | Interest SN WN Z WP SP | Credit SN WN Z WP SP | Mort SN WN Z WP SP | Morb SN WN Z WP SP | Reins SN WN Z WP SP | FX SN WN Z WP SP | Ops SN WN Z WP SP | Exp SN WN Z WP SP | PH SN WN Z |
|---|---|---|---|---|---|---|---|---|---|---|
| Interest Rate | □ ▣ ▣ ▣ ▮ | | | | | | | | | |
| Credit | □ □ ▣ ▣ ▮ | □ □ ▣ ▮ ▣ | | | | | | | | |
| Mortality | □ ▣ ▮ ▣ ▣ | □ ▣ ▮ ▣ ▣ | □ ▣ ▮ ▣ ▣ | | | | | | | |
| Morbidity | □ ▣ ▮ ▣ ▣ | □ □ ▮ ▣ ▣ | □ ▣ ▮ ▣ ▣ | □ ▣ ▣ ▮ □ | | | | | | |
| Counterparty (Reinsurance, Derivative) | □ □ ▣ ▣ ▮ | □ □ ▣ ▮ ▮ | □ □ ▣ ▣ ▮ | □ □ ▮ ▣ ▣ | □ □ ▮ ▣ ▣ | | | | | |
| Foreign Exchange | □ ▣ ▣ ▮ ▣ | □ ▣ ▣ ▮ ▣ | □ ▣ ▣ ▮ ▣ | □ ▣ ▮ ▣ ▣ | □ ▣ ▮ ▣ ▣ | □ ▣ ▣ ▮ ▣ | | | | |
| Operational | □ ▣ ▣ ▮ ▣ | □ ▣ ▣ ▮ ▣ | □ ▣ ▣ ▣ ▣ | □ ▣ ▮ ▮ ▮ | □ ▣ ▮ ▮ ▣ | □ ▣ ▣ ▮ ▣ | □ ▣ ▣ ▮ ▣ | | | |
| Expense | □ ▣ ▣ ▣ □ | □ ▣ ▣ ▣ □ | □ ▣ ▣ ▣ □ | □ ▣ ▣ ▣ □ | □ ▣ ▣ ▣ □ | □ ▣ ▣ ▣ □ | □ ▣ ▣ ▣ □ | □ ▣ ▣ ▣ □ | | |
| Policyholder Behavior | □ □ ▣ ▣ □ | □ □ ▣ ▣ □ | □ □ ▣ ▣ □ | □ □ ▣ ▣ □ | □ □ ▣ ▣ □ | □ □ ▣ ▣ □ | □ □ ▣ ▣ □ | □ □ ▣ ▣ □ | □ □ ▣ ▣ □ | |
| Other (as indicated in Question 6) | □ □ ▣ ▣ □ | □ □ ▣ ▣ □ | □ □ ▣ ▣ □ | □ □ ▣ ▣ □ | □ □ ▣ ▣ □ | □ □ ▣ ▣ □ | □ □ ▣ ▣ □ | □ □ ▣ ▣ □ | □ □ ▣ ▣ □ | □ □ ▣ |

□ A yellow box indicates a response was received for the range
■ A red box indicates the most frequent response for category (e.g. Interest Rate/Equity)