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Case Article

Quantifying Operational Risk in Financial Institutions

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Risk management is essential in today's business environment for banks and other financial institutions to survive in highly competitive and volatile markets. As the subprime mortgage debacle of 2008 has shown us, risk management, or the lack thereof, affects more than just the individual institution. Hence, banks and other financial institutions are subject to frequent reviews by federal regulators. The regulatory reviews require that the institutions set aside capital (cash reserves) to offset the potential risk of loss that they face every day. This case study focuses on a large regional bank, for which we use the pseudonym *A Bank*, and guides students through developing a risk model for operational risk. The students develop their models using maximum likelihood estimation, goodness-of-fit testing, convolution of distributions, and order statistics. The pedagogical objectives of the case study include applying statistics to a real-world problem while establishing connections among statistics, optimization, and simulation. The case can be used in different disciplines such as engineering (e.g., an engineering statistics class) or business (e.g., a hybrid operations research/statistics MBA class or an elective class on quantitative finance) and for graduate or undergraduate education by changing the intensity of the technical skills required and by using a different mix of case documents.

Key words: risk modeling; teaching statistics; maximum likelihood estimation; teaching simulation

History: Received: February 2009; accepted: February 2011.

1. Synopsis of the Case Study

This case is based on analysis conducted at a real bank, for which we use the pseudonym "*A Bank*" throughout the case documents. The case takes place around 2006–2007. *A Bank* is one of the nation's largest bank-based financial services companies. See Table 1 for a list of 20 largest banks in the United States as of May 30, 2008 with respect to their assets. *A Bank* is a bank from this list, although the actual name of the bank is hidden for confidentiality and the data provided was artificially generated by the authors to be similar to the real-world data. Like all financial institutions in the United States, *A Bank* is subject to periodic reviews by federal regulators. These regulatory reviews require *A Bank* to hold cash reserves to offset the potential risk of loss that it faces every day. The case is based on the Basel II international capital accord of the Basel Committee on Banking Supervision that provides guidelines on

how much cash reserves to hold for risk mitigation (Basel Committee 2006).

Risks that banks face everyday can be broadly broken down into four categories:

- (i) credit risk,
- (ii) market risk,
- (iii) strategic risk, and
- (iv) operational risk.

When banks lend a loan or other line of credit, they face the risk of not collecting the money. This is referred to as the credit risk. Market risk, as the name suggests, depends on the economic market and is the risk that the bank's market investments (e.g., stocks, bonds, treasuries, etc.) will decrease because of factors such as changes in stock prices, interest rates, etc. Strategic risk is the risk associated with the bank's future business plans and strategies. Among the four broad categories of risk above, operational risk is a relatively new concept and covers a wide variety of

Table 1 The Largest Banks in the United States, as of March 31, 2008

Rank	Name (city, state)	Assets (in millions)
1	Citigroup (New York, NY)	2,199,848
2	Bank of America Corp. (Charlotte, NC)	1,743,478
3	J. P. Morgan Chase & Company (New York, NY)	1,642,862
4	Wachovia Corp. (Charlotte, NC)	808,575
5	Taunus Corp. (New York, NY)	750,323
6	Wells Fargo & Company (San Francisco, CA)	595,221
7	HSBC North America Inc. (Mettawa, IL)	493,010
8	U.S. Bancorp (Minneapolis, MN)	241,781
9	Bank of the New York Mellon Corp. (New York, NY)	205,151
10	Suntrust, Inc. (Atlanta, GA)	178,986
11	Citizens Financial Group, Inc. (Providence, RI)	161,759
12	National City Bank (Cleveland, OH)	155,046
13	State Street Corp. (Boston, MA)	154,478
14	Capital One Financial Corp. (McLean, VA)	150,608
15	Regions Financial Corp. (Birmingham, AL)	144,251
16	PNC Financial Services Group, Inc. (Pittsburg, PA)	140,026
17	BB&T Corp. (Winston-Salem, NC)	136,417
18	TD Bank North, Inc. (Portland, ME)	118,171
19	Fifth Third Bankcorp (Cincinnati, OH)	111,396
20	Keycorp (Cleveland, OH)	101,596

Notes. The assets are listed in millions of dollars. Data from Federal Reserve System, National Information Center.

risks resulting from inadequate or failed internal processes, people, or systems (insider fraud, data entry errors, hardware and software errors) or from external events (theft, damage to physical assets because of natural disasters, terrorism, or vandalism).

This case study aims to develop a model of the operational risk to find the economic capital *A Bank* needs to hold to offset losses due to operational risks. Market and credit risk models have been well calibrated over the years, however, operational risk is a newer concept and is harder to quantify. A high-quality model of the operational risk is essential to finding the correct amount of capital (cash reserves) to hold. If this capital is too small, then chances of going bankrupt when these events occur increases. If, on the other hand, this capital is too large, the bank loses the opportunity to earn money on excess capital.

The case provides students with data on *number of operational losses* and *amount lost per loss event*. The case then walks students through the process of building an operational risk model using statistics, optimization, and Monte Carlo simulation. First, different probability distributions are considered for both the number of operational losses and the amount of loss per event. The students are required to select the best distribution. The bank is ultimately interested in the *aggregate loss*, which is the total amount of money the bank may lose because of operational risk. Aggregate loss is the sum of amount lost per loss event over the number of losses. This is essentially a random sum of random variables and its distribution typically cannot be written in closed form and has to be simulated.

A Bank is interested in finding the 99.5th percentile of the distribution of the aggregate loss. This will lead to the appropriate level of capital to cover 99.5% of losses due to operational risk.

In summary, the case is an example of a risk management problem faced by financial institutions and helps students to think about modeling of financial risk and exposes them to the use of statistics and other operations research tools such as optimization and simulation for this purpose.

2. Case Documents

The case has five associated documents:

1. Case Article (this document),
2. Case Study,
3. Teaching Note,
4. Excel Analysis Spreadsheet (OpRisk.xlsm; this is a supplemental file), and
5. Slides (only available to instructors).

The *Case Article* (this document) introduces the case and provides a brief history of the case. It also discusses pedagogical objectives of the case, our classroom experience with the case, and it provides recommendations for other possible classroom uses. The *Case Study* is intended for students and classroom use. It contains historical background for the case along with the issues *A Bank* is facing. The *Teaching Note* contains assignment questions, discusses what an instructor should look for in a thoughtful student analysis of the case, and provides solutions and relevant MATLAB code. The *Excel Analysis Spreadsheet* provides an alternative data analysis tool using Excel. The Excel spreadsheet is intended for students to perform several statistical analysis and do Monte Carlo simulation, and it contains instructions on how to use it. The instructors can also use the Excel spreadsheet in the classroom. Finally, the *Slides* provided (in pdf format) can help instructors discuss the case in the classroom.

3. Pedagogical Objectives

3.1. Functional Areas and Analytical Tools Covered

There are four functional areas and analytical tools covered by the case with varying degrees of emphasis: statistics, optimization, simulation, and risk management. The case study has been prepared for and used in the course SIE 430/530: Engineering Statistics, which is offered to both undergraduate and graduate students in the Systems and Industrial Engineering Department at the University of Arizona. Statistics is an indispensable tool in business, engineering, and science for any quantitative analysis that involves randomness. Therefore, teaching a solid knowledge of

statistics and its appropriate use through a real-world problem is the main objective of the case.

The case study relates statistics to other fundamental (operations research/management science) fields such as optimization and simulation. In particular, the case requires students to use nonlinear optimization techniques (e.g., root finding, line searches) for maximum likelihood estimation and confidence interval estimation and simulation techniques (in particular, Monte Carlo simulation) for goodness-of-fit hypothesis testing, order statistics, and confidence interval estimators.

Lastly, the case study aims to quantify operational risk in financial institutions. Risk management, an important and growing field in OR/MS, is essential in today's business environment for banks and other institutions to survive in highly competitive and volatile market environments. Every future manager will be faced with various risk management issues relating to their industry at some point in their career. Therefore, this case study is beneficial for preparing the future leaders of our field and familiarizing them with risk management. We refer the instructors to other cases that specifically deal with the subprime mortgage financial crisis of 2008 (Rotemberg 2008), and its relation to risk management in financial firms from a managerial perspective (Mikes et al. 2010). The case of Sapp (2008), similar to ours, introduces parametric and simulation-based techniques for calculating value at risk.

3.2. Objectives and Skills Reinforced

The case has several pedagogical objectives including: (1) strengthening and expanding upon students' statistical skills in a real-world application; (2) relating statistics to other fundamental OR/MS fields such as optimization and simulation; (3) strengthening computational skills; (4) applying analytical thinking to a real-world problem; and (5) improving "soft" skills such as teamwork, technical writing, and business presentations.

As students progress through the case, they reinforce several statistics skills that are covered in a typical statistics course including maximum likelihood estimation (MLE), chi-squared goodness-of-fit testing, and confidence intervals. However, the case expands on these topics through simultaneous confidence intervals based on the Fisher information matrix, the Kolmogorov-Smirnov (KS) and Anderson-Darling (AD) tests as alternative goodness-of-fit tests, simulating the distribution of an infinite sum of convolutions, and nonparametric confidence interval estimation. The case provides hints and external references to help students utilize these tools in their analysis.

We note that instructors can choose the level of detail and the intensity of statistical and quantitative skills they want to emphasize. For example, the instructor can choose to skip all analytical details and let students use a software tool such as a statistics software or a package with built-in data fitting capabilities such as Crystal Ball or Risk Solver Platform (see §4.2 for more details).

The case also ties together statistics with optimization and simulation while requiring students to devise algorithms and implement them in MATLAB or some other software. Again, we note that instructors can choose the level of detail and the intensity of computational skills they want to reinforce. For instance, instructors who do not wish to use MATLAB can use the provided Excel sheet with built-in macros to perform the data analysis. MLE estimation for many distributions is straightforward. However, the case suggests two probability distributions as models that require numerical procedures to optimize the likelihood function, which can be done using Excel solver or MATLAB. Later in the case, students can program their own optimization procedure to determine a nonparametric confidence interval on the capital estimate. Also, students can implement their own Monte Carlo simulation algorithms to conduct the KS and AD tests.

The case encourages analytical thinking in two main ways. First, real-world problems such as risk management are often complex. The case walks students through decomposing the problem into manageable subproblems, analyzing the subproblems, and recombining them into the final risk model. Although the case focuses on risk modeling, the divide-and-conquer strategy presented here is useful in many other settings. Second, students must choose among competing methods and models. How should we interpret the results of three different goodness-of-fit tests if some of the test results conflict? What is the best model to use? Why? The case brings this analysis to the forefront and requires the students to justify their final conclusions.

Finally, the case develops soft skills such as teamwork and technical writing. The teams practiced their technical writing by completing a final written report of their analysis and findings justifying the decisions they made in their risk models. Students can also be asked to make presentations of their findings, developing their presentation skills.

4. Classroom Use

4.1. Experience

We have used this case for the last two years in an engineering statistics course. One year, we used it as an in-class presentation and discussion to provide an

application of the analytical concepts introduced in the class. We spent one lecture on presentation and discussion after maximum likelihood and goodness-of-fit tests were covered. Our experience with this discussion was very positive. Students enjoyed seeing how the topics covered in the class are used in a real-world setting. Students were also excited about the application area of operational risk. The discussions started with operational risk and its importance and how to analyze it. Then, details of the statistical analysis were discussed. Ample opportunities were given to students to discuss what should the bank do next, how to do it, and how to analyze and interpret the results. We encouraged students to think about and discuss the details of the statistical procedures and pointed out parts that require a more careful analysis and inference.

Another year, we used the case as a three-week end-of-semester project. Approximately one lecture was spent introducing and discussing the case. Then, the students were required to work on the case in teams of two to three students. The class was comprised of M.S. and Ph.D. students (~53% of the class), distance-learning M.S. students (~40%), and advanced undergraduates (~7%). The distance-learning students work for local companies and aim to move to managerial positions. We encouraged on-campus students to form teams with off-campus distance-learning students and undergraduate students to work with graduate students. We believe this is a good way to teach students to work in an environment where some of the coworkers are in different locations and different time zones and have different skill sets. As the real-world work environment becomes more global, it is extremely important to be able to effectively work with colleagues from around the world, whom they might not have met in person. Most groups formed by students had these characteristics but we helped form a couple of the groups to have the desired mix of students.

After the introduction and discussion of the case, students were given three weeks to complete the assignment questions and were asked to provide a written report of their findings and recommendations, together with their analytical solutions. Office hours and question and answer sessions were held to help students. We provided the students with a written discussion of the answers. After students turn in their reports, we recommend spending approximately one lecture, as time permits, to discuss the results of the case.

In our experience with this case, students generally do well on the topics that have been covered in the class (maximum likelihood estimation, chi-squared goodness-of-fit test) and struggle a bit with the newly introduced material (e.g., KS and AD

tests, nonparametric confidence intervals). To help with these, we provided hints and references. For instance, part of the maximum likelihood estimation requires nonlinear optimization of the likelihood function and the nonparametric confidence interval estimation requires a root finding algorithm. After we directed them to well-known root finding techniques (Fries 2007, Venkataraman 2002), many students were able to handle this portion of the project. A small number of students needed further hints on the nonparametric confidence intervals. These hints are provided in the teaching note. In addition, students implemented their algorithms to simulate the KS and AD test statistics and to simulate the aggregate loss distribution to calculate confidence intervals. Students indicated that algorithm development and implementation were the most challenging aspects of the case study but that they learned the most from this. Whereas some students were already fluent in MATLAB, others were not and needed additional time to familiarize themselves. To help with coding, we provided relevant MATLAB functions (see the teaching note) and reminded the students that MATLAB has many built-in functions for statistical analysis. We encouraged the students to examine these functions in detail and experiment with them in order to gain a full understanding of their analysis and statistical inference capabilities. For the KS and AD tests, we referred the students to Sections 1.3.5.16 and 1.3.5.14 of the Engineering Statistics e-Handbook (NIST/SEMATECH 2011) and to other statistics books on this topic (D'Agostino and Stephens 1986). Chapter 10 of Chernobai et al. (2007) also provides a nice technical summary of these tests.

4.2. Intensity of Analytical Skills Required

The intensity of analytical skills required can be adjusted to a desired level. If the instructor wants to focus on risk and operational risk in the banking industry, students can be assigned to read several introductory articles on this topic such as Balin (2008). More details, including technical details, can be found in Chernobai et al. (2007). Relevant chapters from this book (Chernobai et al. 2007) can be assigned as reading. For instance, Chapters 1 and 2 provide an introduction to operational risk and Chapter 3 introduces and discusses the Basel II Capital Accord. The slides provided as part of the case documents can be used in the class to show a real-world application of quantitative analysis for operational risk modeling using statistics. The slides conclude with analytical principles used in the case that can be used in a variety of other applications. The loss distribution approach in the case is essentially a value at risk (VaR) approach. The relative merits and disadvantages of the use of VaR for risk management can enhance the class discussion (Sarykalin et al. 2008).

The intensity of the required technical skills can be increased such that students work on risk modeling but are not required to make any analytical derivations. For statistical analysis and Monte Carlo simulation, the Excel analysis spreadsheet provided as part of the case documents can be used in place of MATLAB. Other alternatives involve using a statistical software package such as SPSS or MINITAB or software with built-in distribution fitting capabilities such as Crystal Ball or Risk Solver Platform. Statistical analysis should involve some exploratory data analysis and graphical tools for goodness of fit such as quantile-quantile plots or probability-probability plots. Tails of the fitted distributions should be paid special attention. Students in programs less intensive in statistics can reference statistics textbooks (Beri 2005, Mittelhammer 1996), although some familiarity with statistics is assumed. For a more detailed quantitative analysis of operational risk in banks with a focus on severity data fitting, students can be referred to Dutta and Perry (2006).

The case can also be used in a high intensity statistics course where emphasis is on analytical derivations, algorithm development, and coding. We recommend using all of the assignment questions in the teaching note in this case. This should be supplemented with classroom discussions on risk, operational risk, and the details of statistical analysis.

Case studies have been successfully used in business schools around the world but this effective method of teaching is much less explored in engineering classrooms. We hope that our case can bridge this gap and provide students a real-world example to practice their newly learned skills.

4.3. Recommendations for Classroom Use

The case's flexibility in analytical intensity and mix of supporting documents provide a rich learning experience suitable for a variety of classroom environments. We provide further guidelines on how to use the case study for different courses and in different ways. We first start by categorizing the course types:

(A) Engineering Graduate: e.g., an engineering statistics course;

(B) Quantitative MBA: e.g., a hybrid OR/statistics course in an MBA program;

(C) Engineering/Business Undergraduate: e.g., an upper-level undergraduate course in statistics, or an undergraduate hybrid course in OR/statistics.

Next, we categorize the different ways the case can be used during a course:

(a) an end-of-semester project with more theory and algorithm emphasis,

(b) an ongoing homework assignment as relevant topics are covered in the lectures,

(c) a case study with less theory and algorithm emphasis,

(d) an in-class discussion.

We now list our recommended uses:

- For an engineering graduate statistics course (type (A) above), we recommend to use the case as a whole in ways (a) or (b), supplemented with (d). In (a), a lecture can be spent introducing and another lecture for discussing the results of the case. In (b), the case can be used throughout the class. When new methods are taught in the classroom, the case can be discussed as an application of these methods. Relevant questions can be assigned as a homework. More advanced questions such as the ones that require coding can be assigned as a shorter project.

- For a quantitative MBA course (type (B) above), we recommend ways (c) and (d), with more in depth classroom discussions. Analytical derivations can be skipped and other software packages can be used. Please see §4.2 for other recommendations and references that can be used to focus on operational risk.

- For an undergraduate course (type (C) above), we recommend ways (b) and (d). Instructors can use the case as an in-class discussion utilizing the slides and Excel sheet. Selected questions (to a desired technical skill level) can be assigned as ongoing homework questions when relevant topics are covered during the course. This can be followed by an in-class discussion to help students relate to the assignments and teach them how to solve real-world problems. We provide further comments for classroom use in the teaching note document.

Supplementary Material

Files that accompany this paper can be found and downloaded from <http://ite.pubs.informs.org/>.

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