FINANCIAL RISK AND FINANCIAL RISK MANAGEMENT TECHNOLOGY (RMT): ISSUES AND ADVANCES

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EXECUTIVE SUMMARY

Methods for sound risk management are of increasing interest among Wall Street investment banking and brokerage firms in the aftermath of the October 1987 crash of the stock market. We present an overview of the basic definitions and issues related to risk, and the management of financial risk and financial risk management technology (**RMT**) for information systems (**IS**) technology professionals. We discuss of the content of risk management technology, including the models, the software and hardware, and the market data required to track risk. We also discuss the identification of risky events, alternative approaches to the measurement of risk, and how investment firms go about formulating strategies to control financial risk.

We next show how changes in the information technologies supporting these tasks have led to improvements in the control of risk and in the design of products which involve financial risk. Advances in five areas that are of interest are: communications software, object-oriented programming, the use of parallel processors and supercomputers, and the application of artificial intelligence and neural nets. Although these new information technologies create significant opportunities to improve global and departmental risk management, a basic question that must be addressed involves the costs associated with their implementation. Thus, a third contribution of this paper is to analyze the extent to which the implementation of these technologies will affect firm costs. To this end, we evaluate the components of the cost function for risk management, and consider some ways that the new technologies can be applied to reduce overall costs.

1. INTRODUCTION

Over the last ten years, major securities firms, money center banks and other commercial and savings banks nationwide have undertaken financial commitments involving risks they did not fully understand, later resulting in major losses and unexpected write offs. As a result, senior managers in these firms are seeking new ways to identify, evaluate and predict changes in financial risks to reduce the likelihood of similar outcomes. Investing in information technologies (**IT**s) that improve the control of risk -- a new area of investment which we refer to as risk management technology (**RMT**) -- is one such approach that is increasingly viewed as having the potential to affect the strategic and competitive position of financial firms.

1.1. Financial Risk Management

In a financial services context, *risk* is defined as "the lack of predictability of outcomes" affecting the set of financial transactions and positions which cumulatively form the firm's business [DOHE85, p. 15]. Thus, risk includes the possibility of both pleasant surprises as well as adverse business outcomes. Since prediction is facilitated by the availability of information to a decision maker, RMT can be used to proactively gauge risk in financial operations, where the outcomes of regional lending operations, involvement in selected financial markets and instruments and positions taken by traders are uncertain and may change from day to day. *Risk management*, on the other hand, is the management of the resources and commitments of a firm so as to maximize its value, taking into account the impact that unpredictable outcomes or events can have on firm performance.

Risk management activities normally involve three basic steps:

(1) exhaustive **identification and classification** of the risks that can impact a firm's business outcomes;

(2) **measurement of the risk** associated with a set of potential events that affect the value of the firm, in terms of the likelihood of their occurrence and the magnitude of the expected losses they may entail;

(3) timely **formulation of the actions** required to bring business risks within acceptable bounds.

The sources of risk that a firm may encounter are varied and depend on the businesses in which it participates.

For example, a financial firm involved in trading financial instruments will face the *market risk* associated with unpredictable price changes of the different financial instruments. A second source is *interest rate risk* arising from interest rate fluctuations, rendering the returns on financial assets uncertain. Interest rate risk also poses significant financial uncertainty when there are gaps in value between the set of claims made on a firm's assets at a specific point in time and the assets' value when the claims are due. With a substantial gap between these values, it may become necessary for the firm to purchase funds in the market at an unexpectedly high cost. Some other types of risk include credit risk and operating risk. *Credit risk* is associated with defaults in repayment of loans by a borrower and *operating risk* stems from frequent changes in or discontinuance of a revenue stream against a continuing level of fixed cost expenditures in the operating infrastructure.

Being able to obtain accurate, up-to-date information is crucial in these risk management contexts. For example, market risk is normally measured by identifying trends of fluctuations in interest rates, and the volatilities of financial instruments and foreign currencies (*Volatility*, here, refers to overnight price changes in an asset's value.) Volatility data on individual financial securities are used in conjunction with data on correlations between the prices of different instruments, and enable the potential for loss in a portfolio to be measured quite objectively. Timely and accurate information about interest rate fluctuations also enables risk managers to gauge the risks associated with maintaining funding gaps. Since senior managers usually draw the line on the maximum risk the firm is willing to undertake in any of its commitments, risk managers and operations managers have similar incentives to take advantage of emerging information technology-based financial management techniques that eliminate excess risk.

1.2. The Role of Information Technology in Risk Management

Information technology has been used pervasively to automate trading activities. Systems that report information about market conditions and market changes, such as Merrill Lynch - Bloomberg for the fixed income market, are also being used to assist traders and portfolio managers. Although a variety of traditional ITs and approaches, including mainframe databases and non-automated tracking of basic market indicators, are still in use, there has been a major move on the part of Wall Street firms towards more sophisticated, state-of-the-art technologies, such as parallel processing, artificial intelligence and neural nets. These ITs are being used by major investment banks with the idea of gaining a competitive advantage in the area of strategic cost management.

There also has been substantial growth in the availability of highly specialized commercial databases, including those from firms such as Reuters/I.P. Sharp and Loanet, that support the tracking of securitized lending portfolios. Apart from supporting the routine activities, commercial databases and computerized financial modeling systems help a trader to manage a portfolio and ward off excess risk by supporting the creation of complex or synthetic securities and the implementation of other hedging strategies that neutralize risk. Creation of securitized loans, for example, allows mortgage loans to be securitized on the basis of the risk involved in their prepayment and their expected return. These mortgage-backed securities can then be freely traded in the market.

At the heart of these developments is the realization by investment banking strategists that IT is crucial in defining the basis of a set of new approaches to conducting money market trading operations. Engineering new financial products that possess attractive risk characteristics for the parties involved in a transaction, as well as the intermediaries to the transaction, is only limited by the willingness of the firm to explore the capabilities of the technologies that support the innovations. Another aspect is the growth in the ability of these firms to manage the risks associated with global investments on a real-time basis from a centralized location. Recent advances in communication technologies and increasingly favorable transmission costs combine to make this possible.

1.3. Outline of the Paper

This paper begins with a basic definition of RMT, and discusses the models, the software and hardware, and the market data required to track risk. We then discuss the identification of risky events, alternative approaches to the measurement of risk, and how investment firms go about formulating strategies to control risk. We next show how rapid changes in ITs supporting these tasks have led to important improvements in the control of risk and in the design of products which involve financial risks for the institutions that offer them. In particular, we will discuss advances in five areas that should be of significant interest to IS professionals:

(1) communications software;

(2) object-oriented programming techniques;

(3) the use of parallel processors and supercomputers to gauge risk in the design of optimal portfolios;

(4) the application of artificial intelligence;

(5) the use of neural nets for predicting market indicators.

Although these new ITs create significant opportunities to improve global and departmental risk management, a basic question that must be addressed involves the costs associated with their implementation. Thus, a third contribution of this paper is to analyze the extent to which the implementation of these technologies will affect firm costs. To this end, we evaluate the components of the cost function for risk management, and consider some ways that the new technologies can be applied to reduce overall costs.

2. INFORMATION TECHNOLOGY APPLIED TO RISK MANAGEMENT PROBLEMS

RMT is defined in terms of three primary components:

(1) analytic models implemented using computer software;

(2) computer hardware for capturing, consolidating and evaluation new information about changing levels of risk; and

(3) the data describing the current and prior states of market.

We commented earlier that risk management activities can be conveniently divided into three categories -- identification and classification of risky events, measurement of risk, and formulation of relevant actions. IT, as we will soon show, can be used to help portfolio managers and traders to do a better job at each of these steps.

2.1. Identification of Risky Events

Many organizations today employ highly sophisticated computerized systems to detect events which can increase their exposure to market risk in their investments. For example, computerized databases of financial information are used to detect changing risks in investment positions. A key element is to identify at the earliest possible time the crucial changes that will affect their business. This is often accomplished with the help of trading platform automation that pulls in digital signals on market indicators, and then scans them to determine if these signals deliver any information that changes the risk profile of current or contemplated investments [MARK90A].

For investments in specific financial instruments, most investment banks today use *risk calculators* to identify risk involved in government securities, such as treasury bonds; in mortgage-backed securities; and in options and foreign exchange (**FX**) trading. Most risk calculators have a simple spreadsheet-type format for carrying out sensitivity analysis, however, a few are more sophisticated. In-house consulting groups in the major investment banking institutions also produce highly specialized tools to discern variations in risk associated with specific financial instruments. For example, the Strategic Technology and Research Group of Manufacturers Hanover Trust was instrumental in the design and development of an expert system called *Trading and Risk Assistant* (**TARA**) that identifies risky transactions in the FX market. Another expert system, developed at Morgan Stanley, is called the *GNMA Trading Assistant* [KEYE90B]. It is a rule-based expert system that helps traders to identify the risks associated with mortgage-backed securities. Both systems identify events that can change the risk baseline for the firm. (We will discuss expert system applications in greater detail in Section 3.4.)

2.2. Categorizing and Measuring Financial Risk

Well-defined measures of financial risk are important for senior management to be able to devise strategies to monitor and evaluate risk. Such measures will enable them to make policies to help departmental traders, operating divisions and the firm as a whole to keep within the acceptable, pre-determined limits. The first step in measuring risk is to develop an understanding of the factors that affect risk (for example, the historical prices of the financial instruments in the case of market risk, and the probability of default in the case of credit risk). Next, the range of fluctuations in these factors from their mean values and the overnight price volatility can be calculated. The measure of volatility determines the riskiness of the financial instrument during the period of observation.

Credit risk is generally measured by tracking information on the credit quality of the parties involved in a credit transaction. This requires the firm to establish a consistent measure of credit exposure as a common denominator across all credit products. For this purpose, all balance sheet items (notes receivable, terms loans and so on), off-balance sheet items (such as standby letters of credit or pending legal commitments), and interest rate and exchange rate contracts (foreign exchange spot and forward trades, interest rate and currency swaps) are converted into a loan equivalent exposure amount. An equity factor is then assigned to each grade of credit risk. This equity factor is used to adjust balance sheet and off-balance sheet exposure to yield *equity at risk.*

IT plays an important role in the measurement of credit risk. Banks usually subscribe to real-time databases that supply information on the credit quality of corporations and banks to which they extend loans. The advantage of a real-time system for monitoring credits is that credit quality updates are instantly available and thus, risk can be monitored on a real-time basis and in the context of decision-making about additional credits. For example, Manufacturers Hanover Trust employs a *Global Exposure System* (GES) that tracks the equity factors assigned to each grade of credit risk, and provides updated credit risk calculations.

Market risk is measured by the fluctuation in prices of instruments due to underlying changes in the market. Adverse movements in FX rates, interest rates, and the extent of the volatility of prices of financial instruments are the most common determinants of market risk. FX positions are exposed to movements in exchange rates and interest rates. Measurement of interest rates fluctuations is important to match the cash flows associated with assets and liabilities that are expected to become due at some future date.

A brief example will serve to illustrate. Suppose a one-year working capital loan is created against a one-month certificate of deposit of similar amount. In this situation, eleven months of additional funding must be generated to match the liability the firm will carry on its books until the expiration of the loan in the twelfth month. The value to the firm of the one-year loan would decrease (increase) at the end of the first month if the interest rates are higher (lower), enabling (forcing) the firm to purchase relatively less (more) expensive funds from certificates of deposit or in the form of overnight Fed funds. Clearly, prevailing interest rates would determine if the firm will be profitable in this kind of lending.

The set of activities involved in ensuring that risk is controlled in these circumstances is called *gap management*. Gap management involves devising strategies and tactics to deal with interest rate risk so that cash flows representing both assets and liabilities are matched. Effective gap management enables a financial institution to protect itself from unexpected and costly borrowing when liabilities exceed assets at some point in time, or eliminates the need for seeking investment opportunities from excess cash balances that arise when assets exceed liabilities.

IT can assist the measurement of interest rate risk and other types of market risk in a significant way. Increasingly available computer software makes it possible to detect the patterns of fluctuations of the most volatile factors and to gauge the extent to which they influence market risk. Identifying and forecasting these patterns and trends is a major step in determining the riskiness of financial instruments, making possible formal evaluation of worst case scenarios. Sophisticated statistical packages can also be used to derive patterns from historical information, which can also be useful in predicting market risk.

Operating risk is measured by two factors: the scale of operations and the flexibility with which the current investments in an operating unit can be used elsewhere in case the unit is shut down. Generally speaking, a complete reorganization of a smaller unit in a firm is more probable than for a bigger unit. Thus, if the fixed operating costs of a small unit within a firm are high, the expected losses due to an overhaul may also be high. IT assists measurement of operating risk by providing advanced database management systems that can gauge the flexibility with which resources can be reallocated within a firm.

Other kinds of financial risk can also be distinguished, measured and controlled. Although different authors have different classification schemes for the various types of risk, some of the more important ones include: shape risk (non-parallel interest rate shifts related to straight default-free securities), sector risk, currency risk and liquidity risk [DAHL89A].

2.3. Formulation of Strategies to Control Risk

Once these types of risks have been measured correctly, they can be represented using common units for comparison purposes. A recent proposal, espoused by Mark (MARK90B), recommends that risk be denominated in terms of *dollars at risk*. Dollars at risk indicates the amount of money at risk in a transaction based on its face value and the probability of the occurrence of a loss. So, for example, if an investment of $1 million is exposed to a 1% risk of loss, then $10,000 is the expected value of the loss or dollars at risk.

Once risk has been converted to a dollar equivalent, the common factors that cause risk for a set of financial instruments can be identified. Most financial instruments exhibit variations in value with changes in factors that affect risk. So, it is possible to combine investments in multiple instruments in such a way that the losses due to adverse changes in risk factors can be compensated for by the gains due to favorable changes. This strategy is widely known as *hedging*, and the final combination of investments selected to produce the "hedge" is called a *portfolio*. Portfolios can be designed by combining various instruments with the objective of keeping overall exposure within certain pre-determined risk limits, while maximizing expected return.

IT plays an important role in the creation of efficient hedges. Although the ratio of investments in different financial instruments can be varied to produce several different hedges, only a few such hedges will be efficient. By definition, *efficient hedges* are those that produce maximum returns on investments for some specified level of risk [WEST86]. To create efficient hedges, the correlations between prices of each instrument in a portfolio must be calculated, and this is normally done through statistical analysis of large financial databases. Common factors that affect risk of multiple financial instruments must also be determined through statistical analysis. The power of IT in this application is to sample the permutations and combinations of instruments so as to enable the design of an efficient hedge. Such computer-aided financial analysis has led to the creation of new and hybrid hedges that were not readily identified using manual analysis.

Thus, we see that IT has advanced financial risk management in a number of ways. We next examine the specifics of risk management applications in areas that are most affected by changes in IT.

3. TECHNOLOGICAL IMPROVEMENTS IN RISK MANAGEMENT

The potential benefits of risk management activities conducted by investment banking and brokerage firms are increasing due to continuing developments in the market for new ITs. We will consider five of the most important ones in this section:

- communication software;
- object-oriented programming and distributed programming;
- parallel processing and supercomputing;
- artificial intelligence; and
- neural nets.

These ITs have been of significant interest to the major accounting firms dealing with risk management in the context of financial auditing [MARO90, KEYE90A].

3.1. Communication Software Advances Pertaining to Risk Management

Attempting to calculate and manage risk on a global basis requires both centralized control of risk computation algorithms and immediate access to large amounts of data detailing both historical statistics and current risk characteristics for each instrument in every portfolio kept by a trading unit of the institution. The problem increases in complexity when one considers that the trading units may be dispersed among markets in multiple time zones. Centralizing risk calculation and providing immediate access to data requires an organization to develop an enabling architecture comprised of database and communication technology. The two main technological approaches to this problem deal with *client-server architectures* and *distributed databases.*

In a client-server architecture, workstations are linked together via a local area network (LAN) with one workstation acting as the database handler (server) for other workstations that request and process information (clients). In this manner, a group of traders can access risk calculations sent to the local network from a centralized mainframe controlled by the headquarters' risk management group. All data necessary for local risk calculation and processing can be staged on the server with "end-of-day" calculations being sent back to the central mainframe. In implementing this approach, an organization can review "end-of-day" risk calculations from each overseas trading office, review the overall dollars at risk, make adjustments to the risk calculation algorithms (if required), and send the new requirements to each node (server) in the system for use beginning on the next trading day (refer to Figure 1). This would allow a form of centralized control with distributed decisionmaking facilitated via the communications technology.

INSERT FIGURE 1 ABOUT HERE

Distributed databases similarly promote distribution of data and decision-making to regional sites, yet take a different technological approach. Whereas client-server architectures allow users at workstations to perceive remote access to a single database as a local access, distributed databases allow concurrent access of two or more remote databases to look like a local access [ROSS91]. This enables an organization to store data on a network wherever it is most economical. It also avoids having to stage the data at each remote database server as in the case of client-server architectures. This way an overseas office can request information on any financial instrument from other sites and does not need to know about all global portfolios that the firm maintains (refer to Figure 1). This concept, *location transparency*, enables an organization to adopt a low cost solution to providing data for risk decisionmaking.

3.2. Object-oriented Databases and Programming Systems

Object-oriented programming languages, such as C++, are rapidly gaining acceptance for software development in the financial world. An *object* is defined as an entity that encapsulates some private state information or data, a set of associated operations or procedures that manipulate the data. A programming language is defined as *object-based* if it supports objects as a language feature and *object-oriented* if it also supports the concept of *inheritance* [CHIN91]. Object-oriented programming languages use the concept of a *class* and an *instance*. A class is the direct extension of an abstract data type; it is a template from which objects may be created. Every object is an instance of some class, and a group of objects that have the same set of operations and the same state representations are considered to be of the same class. Inheritance is a mechanism that allows new classes to be developed from existing classes when the differences between the two classes are stated. To communicate with other objects, an object sends *messages* to those objects. Upon receiving a message from other objects, an object checks to see if the request can be satisfied by using information available within the object. If not, the request is forwarded to other objects which may be able to provide meaningful information.

Security Pacific, for example, is using an object-oriented development environment called *Nexpert Object* to build a system for detecting internal frauds. A number of other business firms are using object-oriented systems for distributed global risk management [O'HE90]. Object-oriented programming is becoming popular in investment banking for decomposing the complex task of monitoring the portfolio of a firm into several simpler tasks of monitoring individual financial instruments.

Different financial instruments fall naturally into different classes: fixed-income investments, options, futures, FX, etc. Under each of these classes, several sub-classes may be specified. For example, fixed-income investments may further be categorized into the sub-classes "bonds" and "mortgages." Each class and sub-class can further have several instances, which in our example will be the names of actual financial instruments. Thus, a "5% coupon Government National Mortgage Association (GNMA) instrument" will be an instance of a mortgage instrument. Each sub-class inherits certain properties from the class from which it is derived. For example, both bonds and mortgages exist for a period of time called their "duration". Duration helps in the calculation of profitability from investments in these financial instruments. Thus, the formula to determine whether an investment in bonds or mortgages is profitable can be put in the "fixed-income instruments" class and inherited by the sub-classes, "bonds" and "mortgages." Messages can be passed from one object to another to gather information pertaining to the current investments in a firm's portfolio. In fact, information that frequently changes, such as FX rates and interest rates, can be grouped together in a separate object with the other objects sending messages to this object if they need updated information.

The nature of risk involved with investments in a financial instrument changes with the type of the instrument. For example, while investments in options usually face market risk, an investment in treasury bonds bears mainly interest rate risk. With the development of an object-oriented system, financial instruments bearing the same type of risk can be easily grouped together under one class, so as to make it convenient for a portfolio manager to identify alternative investments that reduce a particular type of risk. With the addition of an inheritance mechanism, modifications to any class of instruments will only be needed in one place, since all inherited classes will automatically receive this updated information from their parent class.

Another application area where object-oriented systems may prove to be useful in future is that of distributed databases. Invalid or corrupt data is a very serious problem that portfolio managers face when managing global portfolios since the data on financial instruments are gathered from all around the world. Using *distributed object-oriented databases*, a class of portfolios and inherited classes of individual financial instruments can be created at a centralized location. The inheritance mechanism will permit sharing of properties from each class to its inherited classes. This ensures that data for individual financial instruments and the corresponding operations permitted on these instruments are consistent with permissible operations on the firm's portfolio. This becomes more important when data for these financial instruments can be provided at any of several remote offices of a financial institution. One remote office can usually provide updated information on several financial instruments. With the help of a distributed object-oriented system, the updated objects from several remote sites can be shipped to a centralized location, which would then automatically detect data inconsistencies by checking to see if the transmitted objects exhibit some undesirable properties (refer to Figure 2). A distributed object-oriented system can also be used to hide sensitive information by making only a limited number of required objects accessible at specific locations within the firm [KEYE90B].

INSERT FIGURE 2 ABOUT HERE

Among other advantages of such a distributed object-oriented system are fault tolerance (which implies that in cases of failure of local hardware, the loss is restricted to a single object and not to the whole system), and easy recoverability in case of a failure [CHIN91]. Failure of local hardware is not uncommon in the foreign operations of large financial institutions. For global risk management local offices can be asked to maintain only those financial instruments that originate in their markets. Every time an object -- a financial instrument in this case -- is updated by the local office, the updated information can be passed to a centralized location and checked for errors there. Next, this updated information on the object can be passed on to other offices that require information about it. In case of a local failure, only a part of this information will be lost and it can be easily recovered by contacting either the centralized location or other locations wherever the most recent information is available.

3.3. Optimization and Parallel Processing for Financial Risk Management

During the 1970s, significant progress was made by researchers who focused on developing sophisticated management science models to solve a variety of financial management problems, including asset and liability matching, cash flow and position forecasting, float optimization, and so on. Many industry observers, however, have argued that the application of such models to problems of realistic size at large financial firms -- especially where uncertainty about cash flows and interest rates was involved -- required a level of computing power that had not yet become widely available.

Today, the situation is greatly changed. Computing power has increased by several orders of magnitude, and is now readily available in the form of 486-PCs and RISC-based (reduced instruction set computing) engineering workstations. In addition, the advent of massively parallel processing and supercomputing capabilities has fundamentally changed the scope of the models that can be solved. As Stavros Zenios, director of the HERMES Laboratory for Financial Modeling and Simulation at the Wharton School of the University of Pennsylvania has pointed out: "Financial optimization in the 1990s promises to be an area of applications comparable to the use of management science models in logistics, transportation and manufacturing" [ZENI90][1].

From the perspective of financial optimization, risk management can be viewed as "nothing more than taking positions in generic or specific attributes of securities" [DAHL89A, p. 14]. Dahl, Meerus and Zenios describe the difficulties associated with doing this in practice:

> *"An important problem is that generic attributes are not traded in the market! Rather, one can invest in securities, which are in effect packages of attributes. This complicates risk management. For instance, suppose we wish to target a particular exposure to interest rate risk because we expect a parallel downward shift of the yield curve. If we could simply buy a pure duration bond (i.e., one exposed to interest rate risk and nothing else) risk management would be simple. But such a bond is not traded. Instead we can buy a real bond which is simultaneously exposed to interest rate risk and other factors. Targeting duration using one such bond may inadvertently increase [other forms of risk]. This means that comprehensive risk management is faced with the problem of simultaneously controlling the interaction of many securities and their attributes in shaping overall portfolio exposure."* *[DAHL89A, p. 14]*

The use of mathematical programming in this context is a logical choice: it enables the analyst to "optimize" the risk profile associated with a portfolio. Mathematical programming also enables the analyst to realistically represent institutional requirements or limitations placed on investors and their portfolios. Finally, it provides a ready mechanism to formulate a clear objective function for financial risk management, to identify the set of financial instruments in which portfolio selection occurs, and to carry out structured analysis of the relationship between risk and reward.

Such techniques have been successfully applied to a wide variety of financial optimization problems involving risk. These include:

- bond portfolio immunization [BIER82, DAHL89A, FABO89, GRAN84, PLAT86];

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[1]Another indication of the upsurge in interest associated with management science methods for financial optimization that employ powerful computing techniques was evident from the content of a conference on "Mathematical Models in Finance," recently organized by the TIMS College of Financial Modeling, and held at the Stern School of Business, New York University, October 1990.

- bond "factor" immunization (which alters the assumption in bond portfolio immunization that the term structure of interest rates is flat and shifts in parallel) [DAHL89A];

- bond dedication modeling (which alters immunization models to match cash flows "on average" [DAHL89A, ZIPK89];

- downside risk control in option positions [DAHL89A];

- Markowitz models representing the mean and variance of non-systematic risk in portfolios [DAHL89A, INGE87, MARK52, MULV88]; and,

- multi-period stochastic planning models involving uncertainty [BRAD72, DAHL89A, DAHL89B, KUSY86, MULV88];

Areas that have especially benefitted from major advances in the technology used for risk management include mortgage-backed securities (**MBS**) and their derivatives, collateralized mortgage obligations (**CMO**), and other financial instruments that are highly sensitive to interest rates and that involve many cash flows over time. The only way that optimal portfolios can be built based on analysis of these instruments is if the analysis can be carried out in real-time, prior to the expiration of the opportunity or changes in the underlying conditions of the market. Mortgage-backed security portfolio risk management involves modeling mortgage holder behavior as a call option (since a mortgage holder can select to prepay if interest rates change to favor this). The financial optimization problem is to determine what securities to include in an MBS pool with a selected risk profile, and the related lending and borrowing decisions associated with MBS cash flows that either lead or lag the expected cash flow schedule at the time the portfolio was created [ZENI90]. Zenios [ZENI90] reports on the use of a Thinking Machines Inc. "Connection Machine CM-2" massively parallel computing architecture (32,000 processing elements) that takes advantage of recent advances in algorithms for stochastic programming to solve this problem in real-time. In this case, computing power not only supports a business, it anables it.

3.4. Artificial Intelligence (AI) and the Recognition of Patterns Associated with Risk

While the majority of corporate information processing expenditures are in the area of traditional information systems, some organizations have begun to develop expert systems. This technology goes beyond the normal approach of collecting, storing and retrieving data to one of defining human decisionmaking rules (or expertise) and storing those rules along with the data. These systems tend to act as an aid to decision making through the use of stored "knowledge resources" rather than attempt to replace humans with computer automation [PRIE89].

Expert systems can be classified as to their level of knowledge and technological complexity. An expert systems rises on the scale of knowledge complexity as the number of different fields of information required in the decision analysis increases or as the uncertainty of the information, or its completeness, increases. Similarly, an expert system is considered technologically complex if the diversity of platforms (hardware and system software) used for implementing the system is high (refer to Figure 3). A PC-based personal time management program written using an AI shell is an example of an expert system exhibiting low knowledge complexity and low technological complexity. A global risk management system that includes credit, market and operational risk measurement utilizing mainframe distributed databases linked to workstations located around the globe would be one that exhibits both high knowledge and high technological complexity [MEYE91]. An example of the latter is the *Life Underwriting System* by Lincoln National Reinsurance Company, whose goal is to improve organizational profitability through better underwriting risk management. This system includes in-depth knowledge from both the medical and underwriting domains and is supported by multiple technologies and databases [MEYE91].

INSERT FIGURE 3 ABOUT HERE

The uses of AI in financial risk management are numerous:

- Manufacturers Hanover Trust successfully installed an expert system called *TARA* (Technical Analysis and Reasoning Assistant) to assist traders who deal in foreign exchange. The system helped identify patterns associated with foreign exchange rate movements, improving management's ability to identify changing market risk. The flexibility and capability of TARA to explain its reasoning, along with senior management support, were important to its success at Manufacturers Hanover [O'HE90]. Manufacturers Hanover Trust also recently implemented an expert system called *Inspector* that monitors worldwide foreign exchange trading in order to detect irregular activity. The system is considered extremely cost-effective and fits well with existing technologies in the organization, two factors considered important for its success [BYRN90].

- *FXAA* (Foreign Exchange Auditing Assistant) at Chemical Bank was created to provide system support for human auditors in the analysis of trades. Keyes [KEYE90B] reports that the use of FXAA has made auditing of trades more efficient by an astonishing factor of 30.
- The American Stock Exchange is currently experimenting an expert system, *MESS* (Market Expert Surveillance System), to detect cases of insider trading. *MESS* considers thousands of trade transactions daily and is able to shortlist a few of these that it considers may involve insider trading frauds [LUCA90].
- Chase Lincoln Bank developed a planning expert system, the *Chase Personal Financial Planning System*. The system provides financial planning advice to investors and can be used to produce output tailored to specific user interests [KEYE90B].

Another area where AI systems have proved themselves to be useful for financial risk management is *pattern recognition*. Pattern recognition in this context involves analysis of current or historical data on prices, yields or other measures related to specific financial instruments or the market at large to detect patterns that can be used to develop predictive models [ARON85]. The ability of these systems to rapidly process and store data for comparison purposes has given them a competitive edge over humans in recognizing trends and patterns that are useful to control risk. An expert's knowledge can now be coded in a system to infer meaningful predictions from the patterns detected. One example of such a system is PRISM (Pattern Recognition Information Synthesis Modeling) developed by the Raden Research Group. The system has been successfully used to predict changes in the Dow Jones Industrial Average [ARON85].

AI models seem to work best in situations where *semi-structured knowledge* is available to make decisions, a characteristic that fits many financial risk management situations quite well. Most of the rules used in expert systems can be extracted from one or more experts in the trading and treasury domain, though well-defined, structured knowledge (similar to that presented in finance textbooks) may be hard to elicit. In cases where such structured knowledge is available (for example, in programmed trading activities involving cross-market interest rate or market index arbitrage), traditional procedural programming methods have been used to provide fully automated decision support and trade transaction capabilities.

3.5. Neural Nets and the Prediction of Changing Risk

Neural network technology is another innovation that is currently being explored for use in the risk management domain [DUTT88, WHIT88]. Neural networks are computer systems whose internal architectures are designed to imitate biological neural systems. Two main objectives of present-day neural net research are: to duplicate adaptive behavior of humans and to duplicate their capacity to learn new things at a great pace. Neural nets are now being tested in the financial services industry for classification and forecasting purposes. Areas where they could be helpful are: prediction of bankruptcy; forecasting prepayment rates of MBSs; and prediction of stock prices. In contrast to expert systems, neural nets are used in areas where problems are not understood well and the reasoning, as a result is fuzzy. For example, neural nets may prove to be useful for forecasting financial indicators in situations when no universally acceptable forecasting model exists.

Neural nets model massive parallelism and high interconnectivity among a large number of processing units called *neurons*. Each neuron can have multiple inputs and outputs. Generally, neurons are arranged in three layers in a neural net: input, output and hidden. *Input neurons* act as *sensors* and accept all incoming signals. *Output neurons* act as *motoring* units generating the results for a classification scheme. The *hidden layer* comprises neurons that together imitate the complex phenomenon of learning from mistakes and fine-tuning the network so that the predictions achieve more accuracy (refer to Figure 4).

INSERT FIGURE 4 ABOUT HERE

Neural networks usually have two stages: a learning stage and a performing stage [LIPP87]. During the learning phase a network is trained on a part of the data. A subset of the input data set is supplied to the network and a set of predicted output values is obtained from the network. These outputs are next compared with the actual values. Depending on the difference between predicted and actual values, the network is iteratively fine-tuned to reduce this difference. This process is repeated for all observations from the training data set. The resulting neural net can be used to predict values for unknown classification variables (e.g., the prepayment of mortgages, the probability of default of loans, and the likelihood of a firm's going bankrupt), by supplying known values of required input variables to the net.

Neural nets have been shown to perform better than conventional classification techniques (such as regression) in cases where the classification scheme does not have a well-defined model. For example, Dutta and Shekhar [DUTT88] showed that a neural network consistently out-performed a regression model in predicting bond ratings from the given set of financial ratios. Cosset and Roy [COSS88] also showed that neural networks had a higher predictive accuracy than comparable logistic regressions in predicting country risk ratings. Although neural network technology is promising for forecasting financial indicators, one should be cautious in suggesting use of expensive neural net software and hardware when the problem is well-structured enough to permit the use of conventional classification approaches.

Reports of successful neural net applications in industry have sparked rapid growth in their use for solving a variety of classification problems. Some examples are:

- Chase Manhattan Bank developed a neural network application, *ADAM*, in collaboration with Inductive Inference. *ADAM* extracts a collection of Boolean formulas from historical data to determine the borrower's credit-worthiness [MARO90].

- Standard and Poor's successfully used *NeuralWorks Professional* to predict bond price swings [MARO90].

- The *Nestor Character Learning System* is being successfully used in some banks to interpret the dollar amounts scribbled on the face of a check [KEYE90B].

4. RISK MANAGEMENT SYSTEMS: COST-BENEFIT IMPLICATIONS FOR IMPLEMENTING FIRMS

Risk management systems (**RMS**), which are based on RMT, are generally not inexpensive. Sophisticated, large-scale risk management tools can cost anywhere from a few thousand to millions of dollars. Given their high costs, senior management is faced with the difficult task of their payback. To justify these investments, management needs to tie all the benefits of a risk management system to its costs and then evaluate if the cost-benefit ratio meets their expectations. The usual discounted cash flow analysis fails to measure the real benefits of such a system, as most benefits are intangible and uncertain, and can not be converted easily into cash flows.

For example, it is hard to evaluate the benefits of a system which assesses the credit risk of a borrower more accurately than a credit analyst. A credit analyst may be conservative in approving loans and, as a result, may reject some loan applications, that might not have been refused by the system. However, since the loan was not approved, the data on the expected returns of such lost business will not be available when the bank evaluates the benefits of the system. Another example is systems that provide graphical displays. These systems are used to inform a trader about how the market is expected to behave during the course of the day. Although graphics may make it easy for a trader to analyze incoming information, it is very hard to measure the actual benefits of such a system in a field study. Even when the overall profits to a firm are believed to have increased after the use of a system, it is not easy to determine what part of these profits is attributable to the system use. (See Diamond and Kauffman [DIAM89] for additional details.)

4.1. Risk Management Systems: The Dimension of Benefits

Recent advances in IT value research has shown that creation of a *business value linkage* may be useful to understand the scope of the indirect benefits. *Business value* is defined as the economic contribution that IT can make to management's goal of profit maximization in the firm. A business value linkage formalizes the links between IT investments and business value via intermediate productions. A business value linkage for risk management systems involves three primary features:

- identifying all *input costs* or investments needed to install and maintain the system;
- understanding all *intermediate production processes*, both inside and outside the firm, that are affected by the use of the system; and
- Identifying all *business value outputs* whose variations can be attributed to the investments in risk management systems.

Figure 5 provides an illustration of a business value linkage for two risk management systems. The first system in the figure, a risk management forecasting system, has one possible direct output in the form of revenues that might result from the sale of predicted financial indicators in the market. This system can possibly affect the business value outputs from two intermediate production processes, the portfolio management operations and day-to-day trading desk operations. While the business value of the forecasting system from the portfolio management operations will be derived from the value that is generated by better management of risk, business value from trading activities will be derived from the value of the added returns that may result from a knowledge of profitable investment opportunities.

INSERT FIGURE 5 ABOUT HERE

The second system in Figure 5, a distributed object-oriented database system for managing global portfolios, has four possible intermediate production processes from which business value can be realized indirectly. These four production processes are: data hiding control operations, data integrity control operations, portfolio management operations and data mailing operations. By providing limited access of data to users, the system will be able to save losses that may result from inappropriate sharing of information or leakage of information. The system should also be able to reduce operating costs by taking care of data integrity problems. Since the system will obtain updated information in a very short time on all worldwide financial instruments, the firm will be able to control the portfolio risk and increase returns from investments. Finally, in the long run the system should be able to control data mailing costs, further reducing the operating costs.

4.2. Risk Management Systems: The Dimensions of Cost

While a firm typically has to incur costs of several types to manage risk, three types of cost can be identified as important to consider in risk management investments: *fixed costs, variable costs, and opportunity cost.*

Fixed costs include investments in computer hardware, related equipment and the purchase price of the software. If a new risk management system involves complete replacement of existing hardware, it may not be preferred over a system which only needs existing equipment even if the latter system is not considered as good as the former in terms of its performance.

Variable costs include costs of periodic input data feeds required by the system, the costs of periodic preventive and break-down maintenance, costs of software updates etc. Variable cost is dependent on the amount of service requested by the user of these systems. For example, data feeds may be available in several forms: on-line reports; batch reports; daily reports; and monthly or quarterly reports. The actual cost of the data will usually vary depending on a user's choice.

Another dimension of cost involved in the selection of an appropriate risk management system is the opportunity cost of losing business to industry competitors. Opportunity costs arise when profitable risks are not properly identified due to the inadequate performance of a risk management system. Opportunity costs are important here for two reasons. *First*, they form a basis for comparison of performances of different risk management systems. *Second*, unlike other costs, opportunity costs for not using a particular risk management system vary for different firms depending on the nature of their businesses and their current investments. For example, if an investor has not invested in fixed income assets, a risk management system providing in-depth analysis of these assets, will be worth less to him than to an investor who has diversified his investments in whole range of products, including fixed income assets.

4.3. Data Quality: Its Importance in Risk Management System Design

The performance of a risk management system depends importantly on the quality of the data feeds that it utilizes. Very often, data that are updated at more frequent intervals will aid a risk manager in obtaining a more accurate reading of the financial risks faced. Similarly, if the data themselves are accurate and made available with a minimum delay, it is likely that the RMS will provide more value to the user. Work that we currently have underway, however, suggests that some tradeoffs are inevitable, for example, in terms of frequency, response time or accuracy, assuming there is a limited budget [BANS81]. We are utilizing principles from information economics to determine the relative impacts of variations in these system attributes -- variables that are a matter of management choice -- to optimize data quality design decisions.

To evaluate the impacts of variations in quality of data feeds, it is necessary to state all possible forms of data feeds that are to be used as inputs to the particular risk management system. Next, all data quality attributes of these data feeds, such as frequency, response time and accuracy, should be listed. By mocking up the variations in data quality using a sample data set, the decision maker can simulate how a particular risk management model will perform, and examine how far its performance deviates from the optimum performance level with data of the highest quality [BALL85]. Performance here is treated as an objective measure in terms of the specifics of a particular risk management problem. For example, the utility of having a well-hedged portfolio may be one measure of system's performance as the system may be used to hedge a firm's portfolios. In this case, a measure of utility can be used to gauge the objective effectiveness of the hedges. The difference in performance of two potential systems distinguished by different data quality designs gives the difference between the opportunity costs of the systems. The corresponding cost of each data feed should be included with the opportunity cost to yield the total cost for each RMS. These total costs can then be used in the optimization problem described earlier for selecting the appropriate data quality levels that will match the firm's risk management requirements.

4.4. Risk Management Systems: How Should They be Selected?

As a first step towards evaluating risk management systems, managers need to state their current requirements and estimate future needs for computerized tools and the input data feeds. Knowing these requirements, a cost-benefit analysis can be carried out for alternative risk management tools and the data feeds they require.

We recommend the following steps for selecting an appropriate risk management system:

1. *Identify the types of risk your business faces:* Identification of business risk is important to verify if the RMS you are considering will help you manage your business risk.

2. *List all your objectives in using a RMS:* Management usually opts for a RMS with certain objectives in mind. It is essential that all such objectives be listed to make comparison of RMSs easier. Possible objectives of a RMS may be: forecasting foreign exchange patterns, detecting errors in international data entries, checking for trading frauds, etc.

3. *Compile the list of alternative RMSs that can do the job:* This step involves shortlisting those RMSs that satisfy the management's objectives enumerated in Step 2.

4. *Gather all costs associated with a RMS:* For each RMS calculate the fixed and the variable costs.

5. *Sketch a business value linkage diagram for identifying the impacts of the RMS*: For each RMS, identify all intermediate production processes that will get affected by the use of the system. This will

help to turn up hidden or less tangible benefits.

6. *Estimate all direct and indirect business value outputs of the RMS*: Ask the individual intermediate production managers to provide an estimate of business value outputs, e.g., savings in operating costs, value-added by better risk management control, etc. Also estimate the direct revenues that might result from the use of the system. The sum of these direct and indirect benefits also provides a measure of opportunity costs of not using the RMS.

7. *Select the system that has the highest expected benefit to cost ratio.*

5. CONCLUSIONS

We conclude this paper by summarizing the recent advances in risk management technology (**RMT**). We also make the argument that the design of risk management systems is a problem that has a number of interesting dimensions for IS research.

5.1. Synthesis

Advanced information technologies can help in identification, measurement and monitoring of financial risk. With the advent of sophisticated communication and database technology, investments in foreign countries are becoming more tractable and easier to monitor. And, while artificial intelligence is successful in many financial areas, it is now especially used for identification of risky events. Measurement of financial risk under alternative investment scenarios can now be carried out in seconds using parallel computing architectures. Similarly, neural networks have also been used successfully to identify risky events.

The benefits of RMT are obvious, but in many cases, these benefits are intangible or probabilistic. Thus, justification of significant investments in such systems is a difficult task, and the appropriate strategies for justification still need to be established. The paper offers some ideas in this area by suggesting the use of a business value linkage to identify direct and indirect benefits of RMT investments in the intermediate production processes of a financial firm.

This paper also suggests the usefulness of an economics-based approach to selecting the design of risk management systems in terms of three primary components: the data component, the modeling component and the hardware component. In particular, we discussed how data quality optimization can enhance the benefits of a risk management system, while adding relatively few additional costs. We also pointed out that there are oppotunities on the hardware side and the software/modeling side that are made available by recent advances in five relatively new information technologies.

5.2. Risk Management and Information Systems Research

Information systems researchers have a variety of interesting problems to study related to the risk management functions of a firm. These include the design of quality control systems in manufacturing [KEAT91], the optimization of auditing-related efforts, and the application of information systems to gauge and respond to market demand for a firm's products. In each instance, the information a risk management system can provide is crucial: to gauge when a manufacturing process goes out of adjustment, creating future risks for product defect claims; to identify the extent of the evidence required to ensure owners of a firm that they are not subject to the financial risks of poor management; and to determine the extent to which a firm's product revenues are at risk in a changing market. As conditions change, this information will be of significant value to the firm.

Although each of these problems is of an applied nature, we also note that some of the kinds of risks that we outlined above are common across firms and industries. For example, all firms are subject to operating risks. In addition, market risk and credit risk can be readily adapted to reflect the content of different kinds of business scenarios. Market risk in marketing, as an example, may arise from competitor pricing strategies, the entry of new market competitors, and a variety of other factors that are beyond management's control. In software development projects, volatility of returns is an important consideration, especially as the mission of the organization changes or the underlying software development methods evolve.

Future research in the following areas would also be helpful in providing management with additional guidance:

- gauging the effectiveness of alternative RMS models under varying risk management scenarios;
- measuring the business value of RMS;
- examining the relative effectiveness of the new information technologies that were identified

promising candidates to improve the management of risk in the firm;

- combining the capabilities of multiple information technologies to increase the power of the risk management function while controlling costs.

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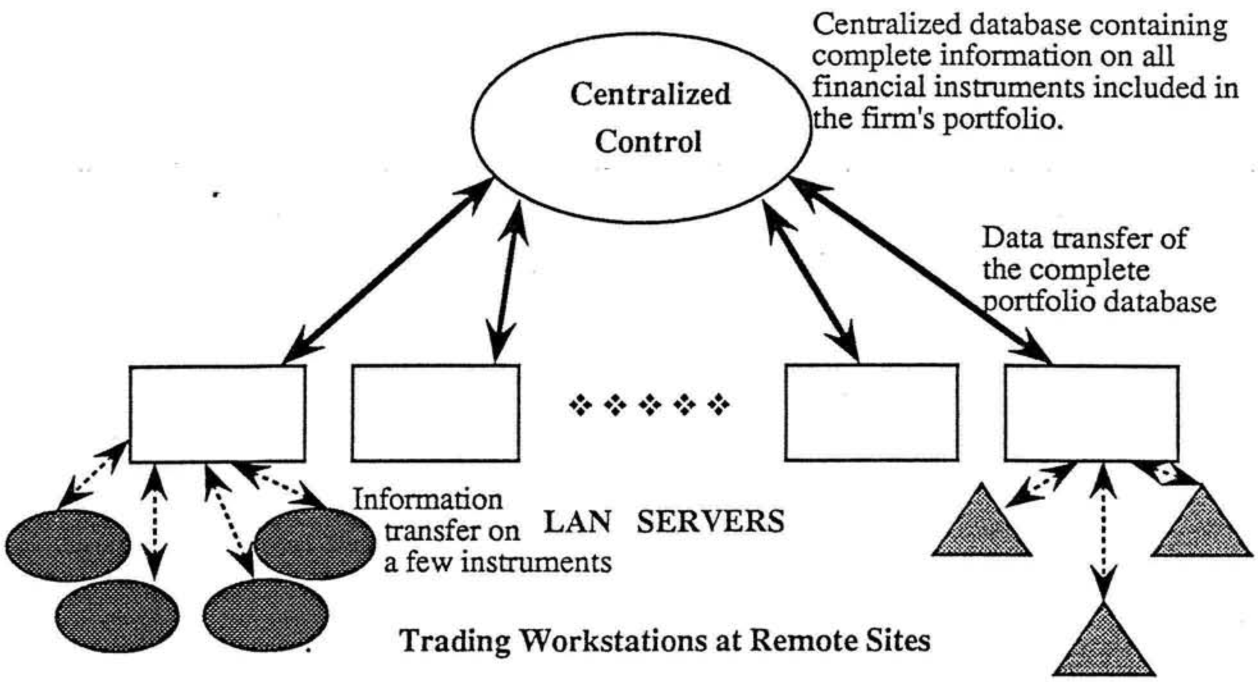
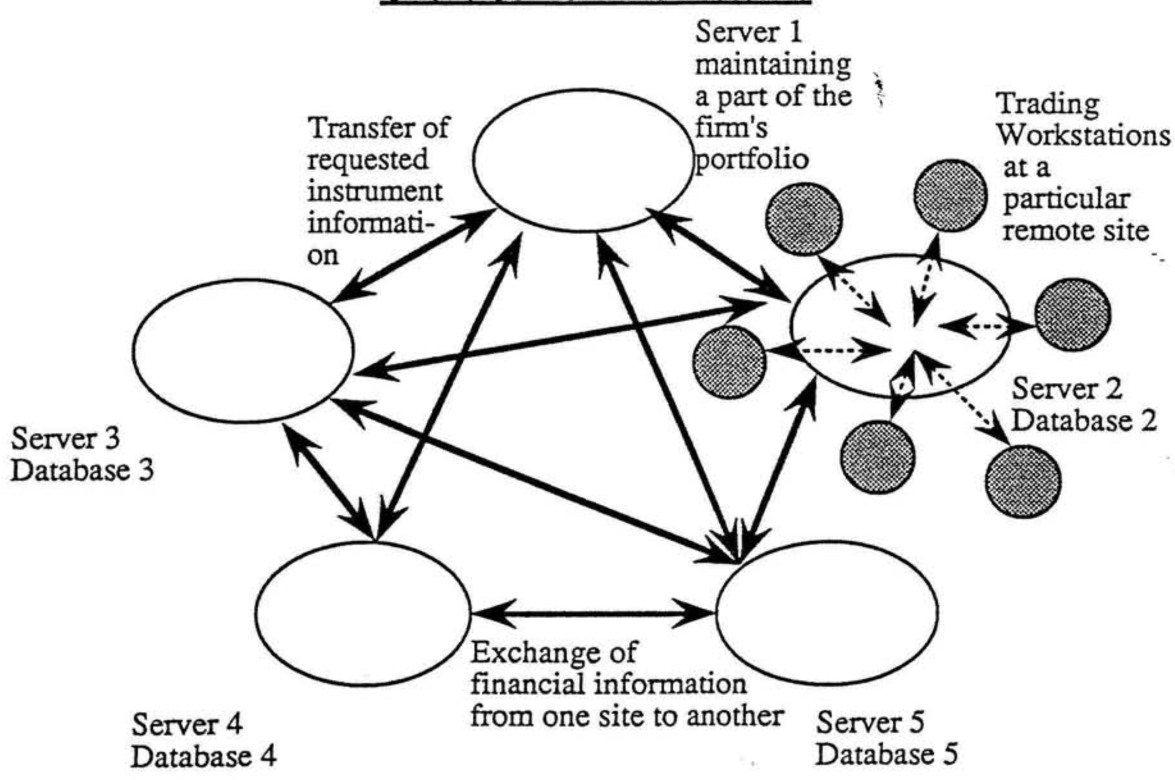
Figure 1: Client-Server Architecture Versus Distributed Databases

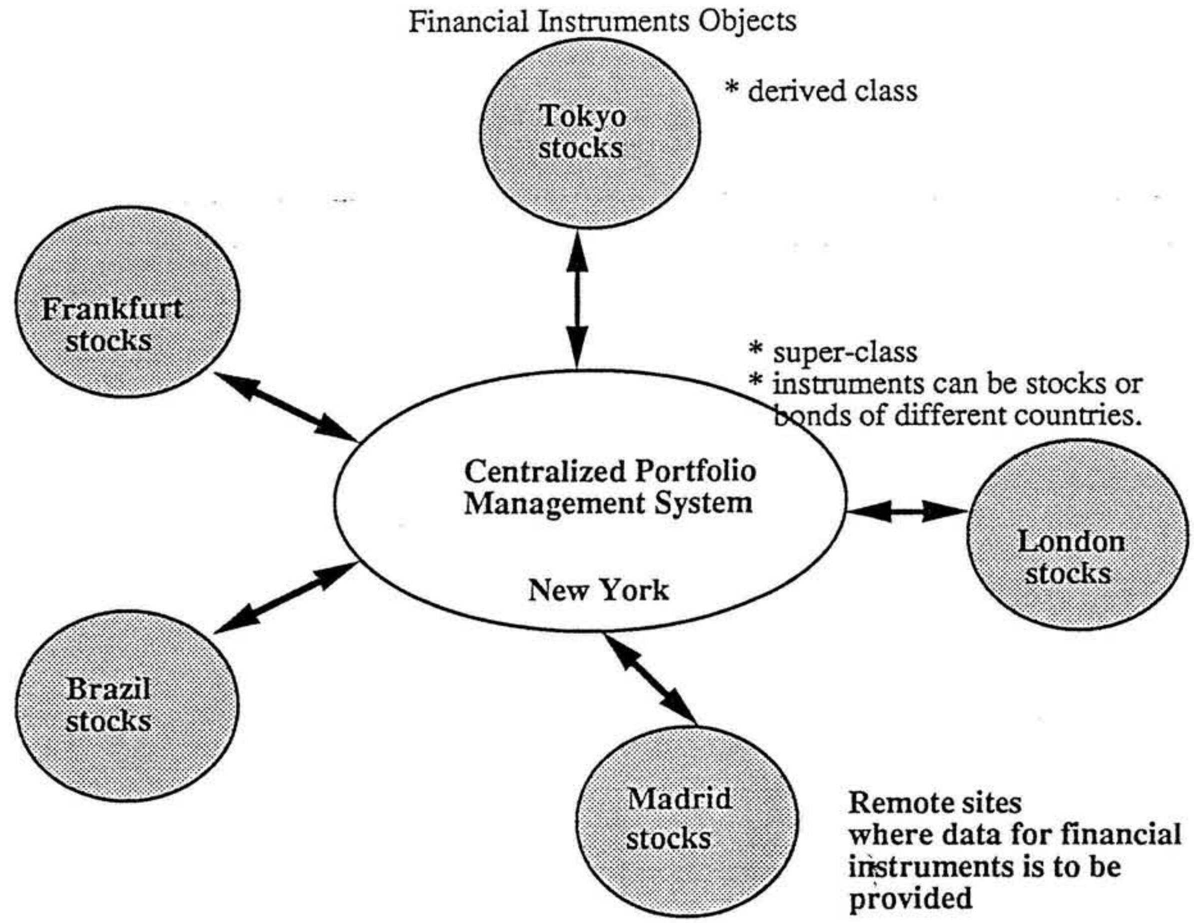


Client-Server Architecture



Distributed Database Technology with Interconnected Servers

Figure 2: An Example of a Distributed Object-Oriented Databases



Characteristics of the derived-class

* permissible inherited operations include: buy/sell.

* inherited properties include: price volatility, correlation and time to maturity.

* individual properties: individual instrument risk, separate instrument properties depending on thetype of the instrument.

* individual operations: country specific-calculations. For example, European options have different calculations than American ones.

* other features that can be included: error checks by making use of permissible range of values for different financial indicators pertaining to a specific instrument.

Characteristics of the super-class

* operations that can be inherited from this class: buy/sell.

* operations that can not be inherited: delete or add an entry of instruments originating in other countries, calculation of risk for all investments.

* properties that can be inherited: price volatility and correlation with other stocks, time to maturity.

* other features include checking for data inconsistencies using certain range checks for portfolio risk.

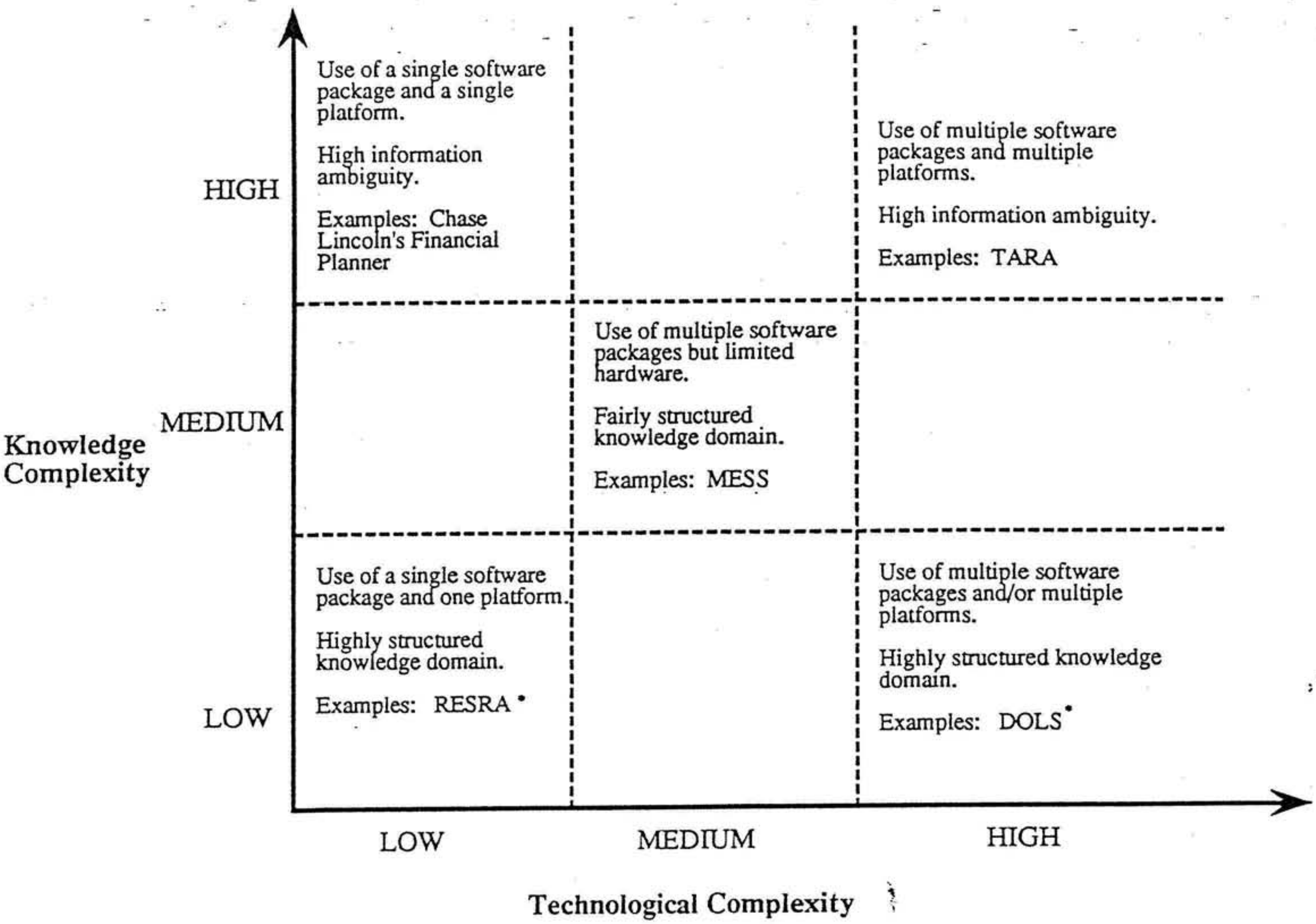
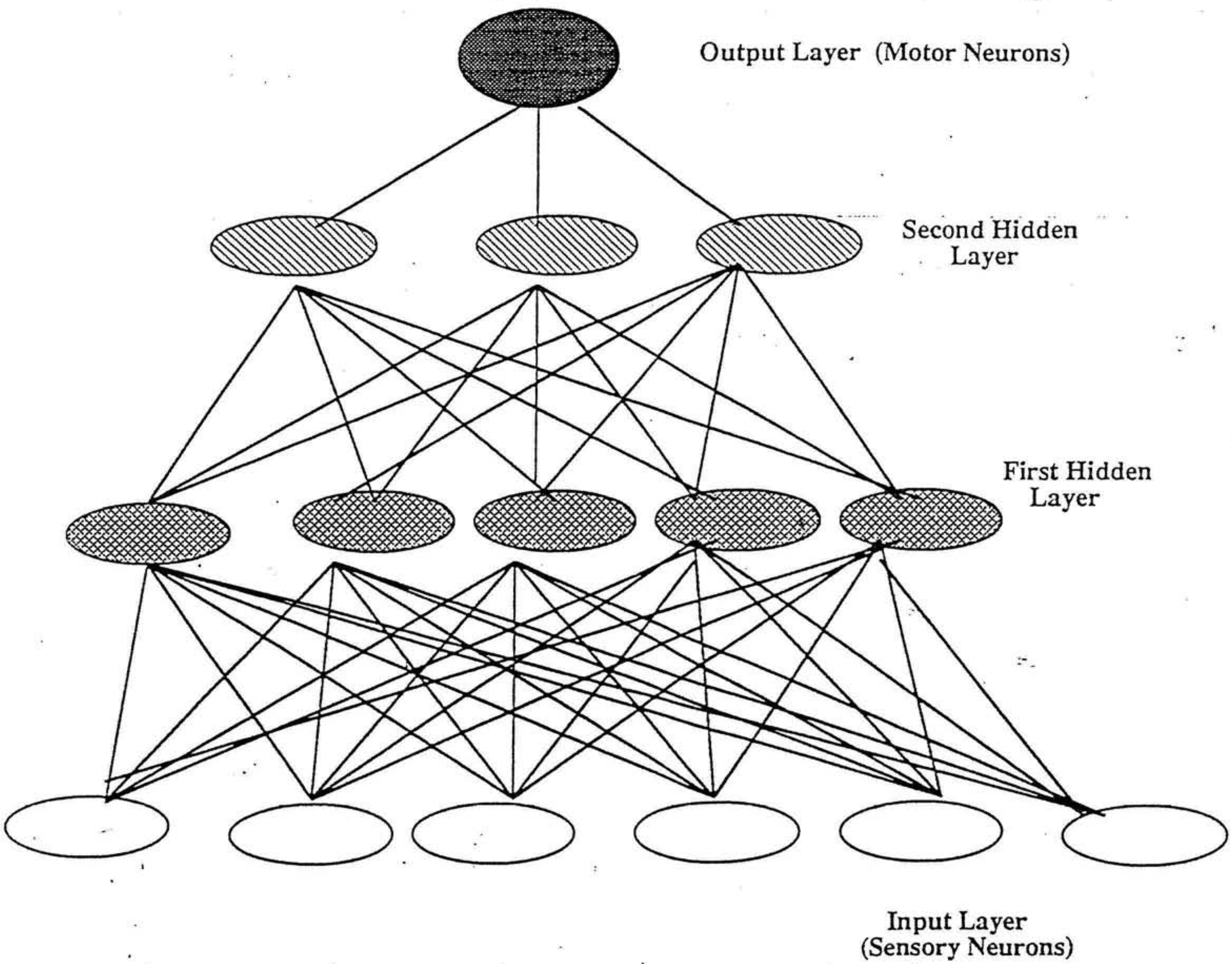


Figure 3: Financial Expert Systems on Knowledge and Technological Complexity Framework

* These systems are not mentioned in Section 3.4. However, a brief description is provided below:

- *RESRA* (Residential Real Estate Appraiser) used by all Security Pacific appraisers in California was designed to remove appraisers biases in deciding whether real estate loans should be approved. This made an objective measurement of credit risk possible [KEYE90B].
- Citibank makes use of an expert system *DOLS* to issue thousands of checks to retirees, and also to make suitable deductions for taxes and pension amounts [KEYE90B].

Figure 4: Architecture of a Neural Network



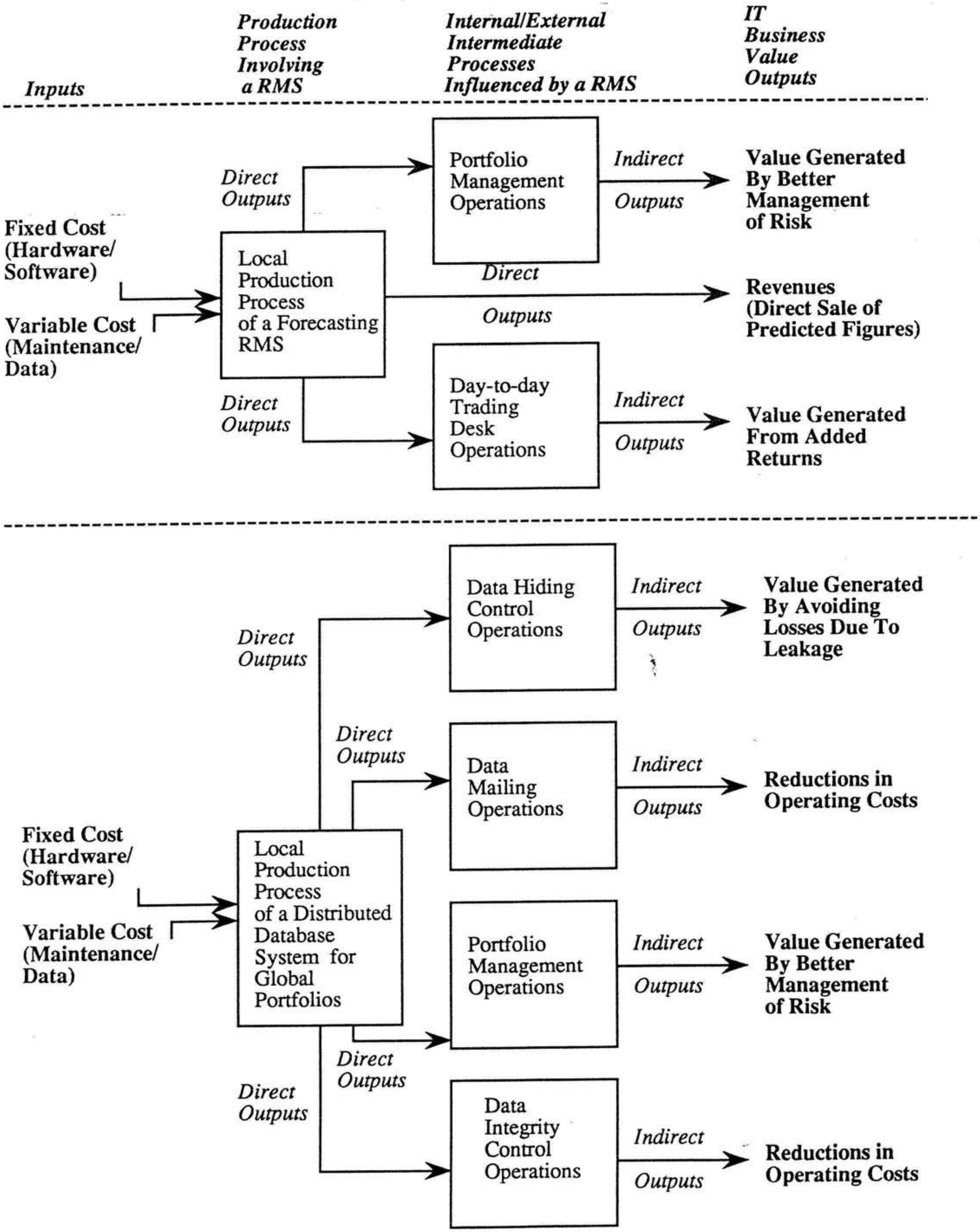


Figure 5: Business Value Linkages for Two Risk Management Systems