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Preface

Enterprise risk management has always been important. However, the events of the twenty-first century have made it even more critical. The top level of business management became suspect after scandals at ENRON, WorldCom, and other business entities. Financially, many firms experienced difficulties from bubbles. The most spectacular failure in the late twentieth century was probably that of Long-Term Capital Management,[1] but that was only a precursor to the more comprehensive failure of technology firms during the dot.com bubble around 2001. The problems of interacting cultures demonstrated risk from terrorism as well, with numerous terrorist attacks, to include 9/11 in the US. Risks can arise in many facets of business. Businesses in fact exist to cope with risk in their area of specialization. But chief executive officers are responsible to deal with any risk fate throws at their organization.

Financial risk management has focused on banking, accounting, and finance. There are many good organizations that have done excellent work to aid organizations dealing with those specific forms of risk. In the past, we have tried to discuss other aspects of risk, to include information systems, disaster management, and supply chain perspectives.[2] In this book, we present more in-depth views of the perspective of supply chain risk management, to include frameworks and controls in the ERM process with respect to supply chains, information systems, and project management. We also discuss aspects of natural disaster management, with focus on China, where we have access to observing some of the financial aspects of risk to supply chain firms.

The bulk of this book is devoted to presenting a number of operations research models that have been (or could be) applied to supply chain risk management. We include decision analysis models, focusing on Simple Multiattribute Rating Theory (SMART) models to better enable supply chain risk managers to trade off conflicting criteria of importance in their decisions. Monte Carlo simulation models are the

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[1] Lowenstein, R. 2000. *When genius failed: The rise and fall of long-term capital management*. New York: Random House.

[2] Olson, D.L., and D. Wu. 2008. *Enterprise risk management*. Singapore: World Scientific Publishing Co.

obvious operations research tool appropriate for risk management. We demonstrate simulation models in supply chain contexts, to include calculation of value at risk. We then move to mathematical programming models, to include chance constrained programming, which incorporates probability into otherwise linear programming models, and data envelopment analysis. We also give a perspective of fuzzy and stochastic (probabilistic) models applied to portfolio selection. Finally, we discuss the use of business scorecard analysis in the context of supply chain enterprise risk management.

Operations research models have proven effective for over half a century. They have been and are being applied in risk management contexts worldwide. We hope that this book provides some view of how they can be applied by more readers faced with enterprise risk.

Contents

Chapter 1
Enterprise Risk Management in Supply Chains

All human endeavors involve uncertainty and risk. Mitroff and Alpaslan (2003) categorized emergencies and crises into three categories: natural disasters, malicious activities, and systemic failures of human systems.[1] *Nature* does many things to us, disrupting our best-laid plans and undoing much of what humans have constructed. Events such as earthquakes, floods, fires and hurricanes are manifestations of the majesty of nature. Recent events to include the tsunami in the Indian Ocean and Hurricane Katrina in New Orleans in 2005 demonstrate how powerless humans can be in the face of nature's wrath.

Malicious acts are intentional on the part of fellow humans who are either excessively competitive or who suffer from character flaws. Examples include Tylenol poisonings of 1982, placing syringes in Pepsi cans in 1993, bombing the World Trade Center in 1993, Sarin gas attacks in Tokyo in 1995, terrorist destruction of the World Trade Center in New York in 2001, and corporate scandals within Enron, Andersen, and WorldCom in 2001. More recent malicious acts include terrorist activities in Spain and London, and in the financial realm, the Ponzi scheme of Bernard Madoff uncovered in 2009. Wars fall within this category, although our perceptions of what is sanctioned or malicious are colored by our biases. Criminal activities such as product tampering or kidnapping and murder blend are clearly not condoned. Acts of terrorism are less easily classified, as what is terrorism to some of us is expression of political behavior to others. Similar gray categories exist in the business world. Marketing is highly competitive, and positive spinning of your product often tips over to malicious slander of competitor products. Malicious activity has even arisen within the area of information technology, in the form of identity theft or tampering with company records.

The third category is probably the most common source of crises: *unexpected consequences arising from overly complex systems*.[2] Examples of such crises include Three Mile Island in Pennsylvania in 1979 and Chernobyl in 1986 within the nuclear power field, the chemical disaster in Bhopal India in 1984, the Exxon Valdez oil spill in 1989, the Ford-Firestone tire crisis in 2000, and the Columbia space shuttle explosion in 2003. The financial world is not immune to systemic failure, as demonstrated by Barings Bank collapse in 1995, the failure of Long-Term Capital Management in 1998, and the sub-prime mortgage bubble implosion leading to near-failure (hopefully no worse than near-failure) in 2008.

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Unexpected Consequences

Charles Perrow contended that humans are creating technologies that are high risk because they are too complex, involving interactive complexity in tightly coupled systems. Examples include am systems, which have provided a great deal of value to the American Northwest and Midwest, but which also create potential for disaster when dams might break; mines, which give access to precious metals and other needed materials but which have been known to collapse; and space activities, which demonstrate some of mankind's greatest achievements, as well as some of its most heartbreaking failures. Nuclear systems (power or weapon) and airline systems are designed to be highly reliable, with many processes imposed to provide checks and balances. Essentially, humans respond to high risk by creating redundant and more complex systems, which by their nature lead to a system prone to greater likelihood of systems failure.

Mitroff and Alpaslan elaborated on systemic crises (Perrow's normal accidents).[3] Within organizations, the spectrum from malicious to system ranges from workplace violence and vandalism through strikes as manifestations of frustrated workers in search of their rights, to simple loss of key employees to competitors. Economies suffer many normal accidents, at the micro level in such forms as hostile takeovers, and at the macro level in forms such as recessions, stock market crashes, bank runs or credit system collapses.

All organizations need to prepare themselves to cope with crises from whatever source. In an ideal world, managers would identify everything bad that could happen to them, and develop a contingency plan for each of these sources of crisis. It is a good idea to be prepared. However, crises by definition are almost always the result of nature, malicious humans, or systems catching us unprepared (otherwise there may not have been a crisis). We need to consider what could go wrong, and think about what we might do to avoid problems. We cannot expect to cope with every contingency, however, and need to be able to respond to new challenges.

This document will focus on supply chain risk management. The next section will review the types of risks faced within supply chains as identified by recent sources. We will then look at processes proposed to enable organizations to identify, react to, and cope with challenges that have been encountered. This will include looking at risk mitigation options. One option explored in depth will be the application of value-focused analysis to supply chain risk. We will then seek to demonstrate points with cases from the literature. We will conclude with an overview.

Supply Chain Risk Frameworks

There is a rapidly growing body of literature concerning supply chain risk management, to include special issues in Journal of Operations Management[4] and in Journal of Supply Chain Management.[5] This literature involves a number of approaches, including some frameworks, categorization of risks, processes, and mitigation strategies. Frameworks have been provided by many, to include Khan and

Burnes[6] who proposed a research agenda to lead empirical support for the many theoretical works they found, and Tang and Tomlin[7] who presented a unified framework around supply chain flexibility. Roth et al.'s[8] framework concerned food recalls from China. Nishat Faisal et al.[9] gave a framework focusing on risk to small and medium-sized enterprises, while Williams et al.[10] did the same for a focus on supply chain security against terrorist acts. Autry and Bobbitt[11] analyzed structured managerial interviews concerning supply chain security, and identified factors most related to those managers' views of supply chain security.

We begin with a general framework. Ritchie and Brindley[12] viewed five major components to a framework in managing supply chain risk.

- Risk context and drivers: Supply chains can be viewed as consisting of primary and secondary levels. The primary level chain involves those that have major involvement in delivery of goods and services (Wal-Mart itself and its suppliers). At the secondary level participants have a more indirect involvement (those who supply vendors who have contracts with Wal-Mart, or Wal-Mart's customers). The primary level participants are governed by contractual relationships, obviously tending to be more clearly stated. Risk drivers can arise from the external environment, from within an industry, from within a specific supply chain, from specific partner relationships, or from specific activities within the organization.

  Risk drivers arising from the external environment will affect all organizations, and can include elements such as the potential collapse of the global financial system, or wars. Industry specific supply chains may have different degrees of exposure to risks. A regional grocery will be less impacted by recalls of Chinese products involving lead paint than will those supply chains carrying such items. Supply chain configuration can be the source of risks. Specific organizations can reduce industry risk by the way the make decisions with respect to vendor selection. Partner specific risks include consideration of financial solvency, product quality capabilities, and compatibility and capabilities of vendor information systems. The last level of risk drivers relate to internal organizational processes in risk assessment and response, and can be improved by better equipping and training of staff and improved managerial control through better information systems.
- Risk management influencers: This level involves actions taken by the organization to improve their risk position. The organization's attitude toward risk will affect its reward system, and mold how individuals within the organization will react to events. This attitude can be dynamic over time, responding to organizational success or decline.
- Decision makers: Individuals within the organization have risk profiles. Some humans are more risk averse, others more risk seeking. Different organizations have different degrees of group decision making. More hierarchical organizations may isolate specific decisions to particular individuals or offices, while flatter organizations may stress greater levels of participation. Individual or group attitudes toward risk can be shaped by their recent experiences, as well as by the reward and penalty structure used by the organization.

- Risk management responses: Each organization must respond to risks, but there are many alternative ways in which the process used can be applied. Risk must first be identified. Monitoring and review requires measurement of organizational performance. Once risks are identified, responses must be selected. Risks can be mitigated by an implicit tradeoff between insurance and cost reduction. Most actions available to organizations involve knowing what risks the organization can cope with because of their expertise and capabilities, and which risks they should outsource to others at some cost. Some risks can be dealt with, others avoided.
- Performance outcomes: Organizational performance measures can vary widely. Private for-profit organizations are generally measured in terms of profitability, short-run and long-run. Public organizations are held accountable in terms of effectiveness in delivering services as well as the cost of providing these services. Kleindorfer and Saad gave 8 key drivers of disruption/risk management in supply chains[13]:

Corporate image
Liability
Employee health and safety
Cost reduction
Regulatory compliance
Community relations
Customer relations
Product improvement

In normal times, there is more of a focus on high returns for private organizations, and lower taxes for public institutions. Risk events can make their preparation in dealing with risk exposure much more important, focusing on survival.

Cases

The research literature is very heavily populated by studies of supply chain risk in recent years. Sodhi and Lee reported risk management at Samsung Electronics,[14] describing the risk-mitigation steps used to deal with risks in all categories of risk appropriate to that firm's operations. Ojala and Hallikas reported experiences in the electronic and metal sector supply chains.[15] Nagali et al. described the process and software developed to measure and manage Hewlett-Packard's procurement risk, including regression-based forecasting and cost minimization optimization models.[16] Schoenherr et al. reviewed a case study of a firm considering Mexican, Chinese, and US alternatives to provide finished goods for a US manufacturer.[17] Khan et al. reported empirical research involving the clothing manufacturing and fashion retail industries.[18] Automotive supply chain cases were reported by Berry and Collier[19] and by Blackhurst et al.[20] Ritchie and Brindley reported risk analysis in a supply chain involving agricultural equipment, as well as a second case involving construction.[21] Zsidisin and Smith reported application of early supplier involvement (ESI) in evaluation and selection of suppliers, along with benefits gained at Rolls Royce.[22] Other reports of aerospace supply chain problems have been reported.[23] Small business participation in supply chains was evaluated in a case involving a Spanish wine operation.[24] Quality management in the form of six sigma operations involving UK Defence Procurement have been discussed.[25] Societal considerations involving economic, environmental and societal objectives were addressed in cases involving oil and genetically engineered food.[26] Note that this is only the tip of the iceberg, meant to give some flavor of the variety of supply chain domains that have been analyzed for risk.

Models Applied

Many different types of models have been proposed in the literature. Because of the uncertainty involved, statistical analysis and simulation is very appropriate to consider supply chain risk. We will only report a few of the many studies, relying on more recent articles. Bayesian analysis has been proposed to model information and knowledge integration within complex networks.[27] Simulation was proposed in a number of studies, to include discrete-event simulation to estimate survival over long-range periods given assumed probabilities of supply chain linkage failure.[28] Wu and Olson used Monte Carlo simulation to evaluate risks associated with vendor selection, following up on similar modeling from many sources.[29] System dynamics models have been widely used, especially with respect to the bullwhip-effect[30] and to model environmental, organizational, and network related risk issues.[31]

Other modeling approaches have been applied to supply chain risk as well. Tang et al. applied a fuzzy genetic algorithm approach to evaluate logistics strategies to lower supply chain risks.[32] As mentioned in the cases section, Hewlett-Packard applies regression models as the basis of forecasting, and optimization models to select how much to purchase from each available source.[33] Bogataj and Bogataj used parametric linear programming based on net present value to estimate supply chain vulnerability.[34] Goh et al. applied a stochastic bi-criterion algorithm to analyze a multi-stage global network problem with objectives of profit maximization and risk minimization.[35] Many studies applied analytic hierarchy process, to include recent studies such as assessment of an offshoring decision,[36] the similar decision to select suppliers,[37] overall supply chain risk evaluation,[38] and inbound supply risk evaluation.[39] Blackhurst et al. presented a study considering multiple objectives for supplier risk assessment utilizing a generic multiple criteria analysis similar to the simple multiattribute rating theory (SMART) method.[40]

Risk Categories Within Supply Chains

Supply chains involve many risks. Cucchiella and Gastaldi divided supply chain risks into categories of internal (involving such issues as capacity variations, regulations, information delays, and organizational factors) and external (market prices, actions of competitors, manufacturing yield and costs, supplier quality, and political issues).[41] Kleindorfer and Saad categorized these into risks arising from coordinating complex systems of supply and demand (internal), and disruptions (external).[42] Specific supply chain risks considered by various studies are given in Table 1.1.

Supply chain organizations thus need to worry about risks from every direction. In any business, opportunities arise from the ability of that organization to deal with risks. Most natural risks are dealt with either through diversification and redundancy, or through insurance, both of which have inherent costs. As with any business decision, the organization needs to make a decision considering tradeoffs. Traditionally,

Table 1.1 Supply chain risk categories

Category	Risk	A	B	C	D	E	F
External							
Nature	Natural disaster: flood, earthquake	X	X		X		X
	Plant fire				X		
	Diseases, epidemics		X				X
Political system	War, terrorism	X			X		X
	Labor disputes	X	X		X		X
	Customs and regulations	X	X	X	X		X
Competitor and market	Price fluctuation			X			
	Economic downturn		X				
	Exchange rate risk	X			X		
	Consumer demand volatility		X	X		X	
	Customer payment	X					
	New technology		X	X			
	Changes in competitive advantage			X			
	Obsolescence	X			X		
	Substitution alternatives				X		
Internal							
Available capacity	Capacity cost	X	X				
	Financial capacity/insurance		X	X			
	Ability to increase production	X		X	X		
	Structural capacity		X	X	X		
	Supplier bankruptcy				X		
Internal operation	Forecast inaccuracy	X	X		X		
	Safety (worker accidents)		X				X
	Bullwhip effect	X		X			
	Agility/flexibility		X	X	X		
	Holding cost/order fulfillment tradeoff	X			X		
	On-time delivery		X		X		
	Quality		X		X		
Information system	IS breakdown	X					
	Distorted information				X		X
	Integration	X			X		X
	Viruses/bugs/hackers		X		X		X

A – Chopra and Sodhi (2004)[43]; B – Wu et al. (2006)[44]; C – Cucchiella and Gastaldi (2006)[45]; D – Blackhurst et al. (2008)[46]; E – Manuj and Mentzer (2008)[47]; F – Wagner and Bode (2008).[48]

this has involved the factors of costs and benefits. Society is more and more moving toward even more complex decision-making domains requiring consideration of ecological factors as well as factors of social equity.

Dealing with other external risks involves more opportunities to control risk sources. Some supply chains in the past have had influence on political systems. Arms firms like that of Alfred Nobel come to mind, as well as petroleum businesses, both of which have been accused of controlling political decisions. While most supply chain entities are not expected to be able to control political risks to include wars and regulations, they do have the ability to create environments leading to labor unrest. Supply chain organizations have even greater expected influence over economic factors. While they are not expected to be able to control exchange rates, the benefit of monopolies or cartels is their ability to influence price. Business organizations also are responsible to develop technologies providing competitive advantage, and to develop product portfolios in dynamic markets with product life cycles. The risks arise from competitors' abilities in never-ending competition.

Internal risk management is more directly the responsibility of the supply chain organization and its participants. Any business organization is responsible to manage financial, production, and structural capacities. They are responsible for programs to provide adequate workplace safety, which has proven to be cost-beneficial to organizations as well as fulfilling social responsibilities. Within supply chains, there is need to coordinate activities with vendors, and to some degree with customers (through bar-code cash register information providing instantaneous indication of demand). Information systems technology provides a new era of effective tools to keep on top of supply chain information exchange. Another factor of great importance is the responsibility of supply chain core organizations to manage risks inherent in the tradeoff between wider participation made possible through Internet connections (providing a larger set of potential suppliers leading to lower costs) with the reliability provided by long-term relationships with a smaller set of suppliers that have proven to be reliable.

Process

A process is a means to implement a risk management plan. Cucchiella and Gastaldi outlined a supply chain risk management process[49]:

- Analysis: examine supply chain structure, appropriate performance measures, and responsibilities
- Identify sources of uncertainty: focus on most important
- Examine risks: select risks in controllable sources of uncertainty
- Manage risk: develop strategies
- Individualize most adequate real option: select strategies for each risk
- Implement

This can be combined with a generic risk management process compatible with those provided by Hallikas et al., Khan and Burnes, Autry and Bobbitt, and by Manoj and Mentzer[50]:

- Risk identification
  - Perceiving hazards, identifying failures, recognizing adverse consequences
  - Security preparation and planning
- Risk assessment (estimation) and evaluation
  - Describing and quantifying risk, estimating probabilities
  - Estimating risk significance, acceptability of risk acceptance, cost/benefit analysis
- Selection of appropriate risk management strategy
- Implementation
  - Security-related partnerships
  - Organizational adaptation
- Risk monitoring/mitigation
  - Communication and information technology security

Both of these views match the Kleindorfer and Saad risk management framework of[51]:

1. The initial requirement is to specify the nature of underlying hazards leading to risks;
2. Risk needs to be quantified through disciplined risk assessment, to include establishing the linkages that trigger risks;
3. To manage risk effectively, approaches must fit the needs of the decision environment;
4. Appropriate management policies and actions must be integrating with on-going risk assessment and coordination.

In order to specify, assess and mitigate risks, Kleindorfer and Saad proposed ten principles derived from industrial and supply chain literatures:

1. Before expecting other supply chain members to control risk, the core activity must do so internally;
2. Diversification reduces risk – in supply chain contexts, this can include facility locations, sourcing options, logistics, and operational modes;
3. Robustness to disruption risks is determined by the weakest link;
4. Prevention is better than cure – loss avoidance and preemption are preferable to fixing problems after the fact;
5. Leanness and efficiency can lead to increased vulnerability;
6. Backup systems, contingency plans, and maintaining slack can increase the ability to manage risk;
7. Collaborative information sharing and best practices are needed to identify vulnerabilities in the supply chain;

8. Linking risk assessment and quantification with risk management options is crucial to understand potential for harm and to evaluate prudent mitigation;
9. Modularity of process and product designs as well as other aspects of agility and flexibility can provide leverage to reduce risks, especially those involving raw material availability and component supply;
10. TQM principles such as Six-Sigma give leverage in achieving greater supply chain security and reduction of disruptive risks as well as reducing operating costs.

Mitigation Strategies

There are many means available to control risks within supply chains. A fundamental strategy would be to try to do a great job in the fundamental supply chain performance measures of consistent fulfillment of orders, delivery dependability, and customer satisfaction. That basically amounts to doing a good job at what you do. Of course, many effective organizations have failed when faced with changing markets or catastrophic risks outlined in the last section as external risks. Some strategies proposed for supply chains are reviewed in Table 1.2.

Chopra and Sodhi developed a matrix to compare relative advantages or disadvantages of each strategy with respect to types of risks.[52] Adding capacity would

Table 1.2 Supply chain mitigation strategies

Chopra and Sodhi (2004)	Tang (2006)	Khan and Burnes (2007)	Wagner and Bode (2008)	Manoj and Mentzer (2008)
Add capacity	Make and BUY revenue management			Expand where you have competitive advantage
Add inventory	Strategic stock	Buffers		
Redundant suppliers		Multiple sources	Monitor suppliers	Drop troublesome suppliers
Increase responsiveness		Information sharing	Contingency planning	
Increase flexibility	Product postponement	Product differentiation	Late product differentiation	Delay resource commitment
Pool demand	Flexible supply base			
Increase capability				Outsource low probability demand
More customers				
		Early supplier involvement	Information sharing	Sharing/transfer
		Risk taking	Insurance	Hedge (insure, disperse globally)
				Drop troublesome customers

be expected to reduce risk of needing more capacity of course, and also decrease risk of procurement and inventory problems, but increases the risk of delay. Adding inventory is very beneficial in reducing risk of delays, and reduces risk of disruption, procurement, and capacity, but incurs much greater risk of inventory-related risks such as out-dating, spoilage, carrying costs, etc. Having redundant suppliers is expected to be very effective at dealing with disruptions, and also can reduce procurement and inventory risk, but can increase the risk of excess capacity. Other strategies had no negative expected risk impacts (increasing responsiveness, increasing flexibility, aggregating demand, increasing capability, or increasing customer accounts), but could have negative cost implications.

Tang emphasized robustness.[53] He gave nine robust supply chain strategies, some of which were included in Table 1.2. He elaborated on the expected benefits of each strategy, both for normal operations as well as in dealing with major disruptions, outlined in Table 1.3, organized by purpose.

Cucchiella and Gastaldi gave similar strategies, with sources of supply chain research that investigated each.[54] Cucchiella and Gastaldi expanded Tang's list to include expansion of capacity. Ritchie and Brindley included risk insurance, information sharing, and relationship development.[55]

Table 1.3 Tang's robust supply chain strategies

Strategy	Purpose	Normal benefits	Disruption benefits
Strategic stock	Product availability	Better supply management	Quick response
Economic supply incentives	Product availability	Better supply management	Can quickly adjust order quantities
Postponement	Product flexibility	Better supply management	Can change product configurations quickly in response to actual demand
Flexible supply base	Supply flexibility	Better supply management	Can shift production among suppliers quickly
Make-and-buy	Supply flexibility	Better supply management	Can shift production in-house or outsource
Flexible transportation	Transportation flexibility	Better supply management	Can switch among modes as needed
Revenue management	Control product demand	Better demand management	Influence customer selection as needed
Dynamic assortment planning	Control product demand	Better demand management	Can influence product demand quickly
Silent product rollover	Control product exposure	Better manage both supply and demand	Quickly affect demand

Conclusions

Enterprise risk management began focusing on financial factors. After the corporate scandals in the US in the early 2000s, accounting aspects grew in importance. This chapter discusses the importance of risk management in the context of supply chain management.

A representative risk framework based on the work of Ritchie and Brindley was presented. It rationally begins by identify causes (drivers) of risk, and influencers within the organization. Those responsible for decision making are identified, and a process outlined where risks, responses, and measures of outcomes are included.

There have been many cases involving supply chain risk management reported recently. These are briefly reviewed, along with quantitative modeling presented. The chapter uses multiple criteria models to demonstrate analysis of supply chain risk. Typical risks faced by supply chains are extracted from six sources, and categorized. A process of risk identification, assessment, strategy development and selection, implementation and monitoring is reviewed. Representative strategies were extracted from four published sources, and a method for evaluation of strategy robustness reviewed.

We will next demonstrate use of value-focused risk analysis in supply chains, incorporating the multiple criteria ideas presented in this chapter in a more concrete form.

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Chapter 2
Enterprise Risk Management Process

Enterprise risk management (ERM) has become very important. The financial world is not immune to systemic failure, as demonstrated by many stories such as Barings Bank collapse in 1995, the failure of Long-Term Capital Management in 1998, and a handful of bankruptcy cases in the current financial crisis, e.g., the federal government's takeover of Fannie Mae and Freddie Mac and the fall of Lehman fell and Merrill Lynch. There is no doubt that risk management is an important and growing area in the uncertain world.

Smiechewicz[1] gave a framework for ERM, relying on top management support within the organization. Many current organizations have chief risk officers (CROs) appointed, but the effectiveness of risk management depends on active participation of top management to help the organization survive the various risks and crises they encounter.

Set risk appetite
Risk identification process
Identify risks
Develop risk matrix
Risk management process
Risk review processes

The first step is to *set the risk appetite* for the organization. No organization can avoid risk. Nor should they insure against every risk. Organizations exist to take on risks in areas where they have developed the capability to cope with risk. However, they cannot cope with every risk, so top management needs to identify the risks they expect to face, and to identify those risks that they are willing to assume (and profit from successfully coping).

The *risk identification* process needs to consider risks of all kinds. Typically, organizations can expect to encounter risks of the following types:

- Strategic risk
- Operations risk
- Legal risk
- Credit risk
- Market risk

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Table 2.1 Enterprise risk management framework

Strategic risks	Is there a formal process to identify potential changes in markets, economic conditions, regulations, and demographic change impacts on the business? Is new product innovation considered for both short-run and long-run impact? Does the firm's product line cover the customer's entire financial services experience? Is research and development investment adequate to keep up with competitor product development? Are sufficient controls in place to satisfy regulatory audits and their impact on stock price?
Operations risks	Does the firm train and encourage use of rational decision-making models? Is there a master list of vendor relationships, with assurance each provides value? Is there adequate segregation of duties? Are there adequate cash and marketable securities controls? Are financial models documented and tested? Is there a documented strategic plan to technology expenditures?
Legal risks	Are patent requirements audited to avoid competitor abuse as well as litigation? Is there an inventory of legal agreements and auditing of compliance? Do legal agreements include protection of customer privacy? Are there disturbing litigation patterns? Is action taken to assure product quality sufficient to avoid class action suits and loss of reputation?
Credit risks	Are key statistics monitoring credit trends sufficient? How are settlement risks managed? Is their sufficient collateral to avoid deterioration of value? Is the incentive compensation program adequately rewarding loan portfolio profitability rather than volume? Is exposure to foreign entities monitored, as well as domestic entity exposure to foreign entities?
Market risks	Is there a documented funding plan for outstanding lines? Are asset/liability management model assumptions analyzed? Is there a contingency funding plan for extreme events? Are core deposits analyzed for price and cash flow?

Examples of these risks within Smiechewicz's framework are outlined in Table 2.1.

Each manager should be responsible for ongoing risk identification and control within their area of responsibility. Once risks are identified, a risk matrix can be developed. Risk matrices will be explained in the next section. The *risk management* process is the control aspect of those risks that are identified. The adequacy of this process depends on assigning appropriate responsibilities by role. It can be monitored by a risk-screening committee at a high level within the organization that monitors new significant markets and products. The *risk review* process includes a systematic internal audit, often outsourced to third party providers responsible for ensuring that the enterprise risk management structure functions as designed.

Risk Matrix

A risk matrix provides a two-dimensional (or higher) picture of risk, either for firm departments, products, projects, or other items of interest. It is intended to provide a means to better estimate the probability of success or failure, and identify those activities that would call for greater control. One example might be for product lines, as shown in Table 2.2.

Table 2.2 Product risk matrix

	Likelihood of risk low	Likelihood of risk medium	Likelihood or risk high
Level of risk high	Hedge	Avoid	Avoid
Level of risk medium	Control internally	Hedge	Hedge
Level of risk low	Accept	Control internally	Control internally

The risk matrix is meant to be a tool revealing the distribution of risk across a firm's portfolio of products, projects, or activities, and assigning responsibilities or mitigation activities. In Table 2.2, hedging activities might include paying for insurance, or in the case of investments, using short-sale activities. Internal controls would call for extra managerial effort to quickly identify adverse events, and take action (at some cost) to provide greater assurance of acceptable outcomes. Risk matrices can represent continuous scales. For instance, a risk matrix focusing on product innovation was presented by Day.[2] Many organizations need to have an ongoing portfolio of products. The more experience the firm has in a particular product type, the greater the probability of product success. Similarly, the more experience the firm has in the product's intended market, the greater the probability of product success. By obtaining measures based on expert product manager evaluation of both scales, historical data can be used to calibrate prediction of product success. Scaled measures for product/technology risk could be based on expert product manager evaluations as demonstrated in Table 2.3 for a proposed product, with higher scores associated with less attractive risk positions.

Table 2.4 demonstrates the development of risk assessment of the intended market.

Table 2.5 combines these scales, with risk assessment probabilities that should be developed by expert product managers based on historical data to the degree possible.

In Table 2.5, the combination of technology risk score of 18 with product failure risk score 26 is in bold, indicating a risk probability assessment of 0.30.

Table 2.3 Product/technology risk assessment

	1 – Fully experienced	2	3 – Significant change	4	5 – No experience	Score
Current development capability			X			3
Technological competency		X				2
Intellectual property protection				X		4
Manufacturing and service delivery system	X					1
Required knowledge			X			3
Necessary service		X				2
Expected quality			X			3
Total						18

Table 2.4 Product/technology failure risk assessment

	1 – Same as present	2	3 – Significant change	4	5 – Completely different	Score
Customer behavior				X		4
Distribution and sales			X			3
Competition					X	5
Brand promise					X	5
Current customer relationships					X	5
Knowledge of competitor behavior				X		4
Total						26

Table 2.5 Innovation product risk matrix expert success probability assessments

	Failure <10	Failure 10–15	Failure 15–20	Failure 20–25	Failure 25–30
Technology 30–35	0.50	0.40	0.30	0.15	0.01
Technology 25–30	0.65	0.50	0.45	0.30	0.05
Technology 20–25	0.75	0.60	0.55	0.45	0.20
Technology 15–20	0.80	0.70	0.65	0.55	**0.30**
Technology 10–15	0.90	0.85	0.80	0.65	0.45
Technology <10	0.95	0.90	0.85	0.70	0.60

Risk matrices have been applied in many contexts. In the medical field, Blomeyer et al.[3] presented a risk matrix for child development, focused on predicting basic cognitive, motor and noncognitive abilities based on the two dimensions of organic risk factors and psychosocial risk factors. McIlwain[4] cited the application of clinical risk management in the United Kingdom arising from the National Health Service Litigation Authority creation in April 1995. This triggered systematic analysis of incident reporting on a frequency/severity grid comparing likelihood and consequence. Traffic light colors are often used to categorize risks into three (or more) categories, quickly identifying combinations of frequency and consequence calling for the greatest attention. Table 2.6 gives a possible risk matrix.

Table 2.6 Risk matrix of medical events

	Consequence insignificant	Consequence minor	Consequence moderate	Consequence major	Consequence catastrophic
Likelihood almost certain	Amber	Red	Red	Red	Red
Likelihood likely	Green	Amber	Red	Red	Red
Likelihood possible	Green	Amber	Amber	Amber	Red
Likelihood unlikely	Green	Green	Amber	Amber	Red
Likelihood rare	Green	Green	Green	Amber	Amber

Table 2.6 demonstrates the use of a risk matrix that could be based on historical data, with green assigned to a proportion of cases with serious incident rates below some threshold (say 0.01), red for high proportions (say 0.10 or greater), and amber in between.

While risk matrices have proven useful, they can be misused as can any tool. Cox[5] provided a critique of some of the many risk matrices in use. Positive examples were shown from the Federal Highway Administration for civil engineering administration (Table 2.7), and the Federal Aviation Administration applied to airport operation safety.

The Federal Aviation Administration risk matrix was quite similar, but used qualitative terms for the likelihood categories (frequent, probable, remote, extremely remote, and extremely improbable) and severity categories (no safety effect, minor, major, hazardous, and catastrophic). Cox identified some characteristics that should be present in risk matrices:

1. Under weak consistency conditions, no red cell should share an edge with a green cell
2. No red cell can occur in the left column or in the bottom row
3. There must be at least three colors
4. Too many colors give spurious resolution

Table 2.7 Risk matrix for federal highway administration (2006)

	Very low impact	Low impact	Medium impact	High impact	Very high impact
Very high probability	Green	Yellow	Red	Red	Red
High probability	Green	Yellow	Red	Red	Red
Medium probability	Green	Green	Yellow	Red	Red
Low probability	Green	Green	Yellow	Red	Red
Very low probability	Green	Green	Green	Yellow	Red

Extracted from Cox (2008).

Cox argued that risk ratings do not necessarily support good resource allocation decisions. This is due to the inherently subjective categorization of uncertain consequences. Thus Cox argues that theoretical results he presented demonstrate that quantitative and semiquantiative risk matrices (using numbers instead of categories) cannot correctly reproduce risk ratings, especially if frequency and severity are negatively correlated.

Information System Risk Matrix Application

Egerdahl[6] presented a risk matrix to support data processing audit functions. The purpose was to identify *threats* facing the environment, the facility *components*, and appropriate *controls*.

Steps in building the IT auditing risk matrix included:

1. Identify threats and components
2. Identify necessary controls
3. Place appropriate controls in matrix cells
4. Rank and evaluate control adequacy

Threats were potentially adverse events such as lost or corrupted data, outages of system components, theft, or disasters. Example threats included:

- Alteration – unauthorized changes to the system
- Costs – excessive or inappropriate
- Denial of service – destruction, damage, or other events making system unavailable to users
- Destruction – outages of system components
- Errors and omissions – system degradation leading to erroneous output
- Fraud – theft of system component, or access to defraud

- Regulatory exposure – system performance leading to government or customer suits
- System malfunction – performance other than intended, from bugs, poor design, or other factors
- Unauthorized disclosure – unauthorized access through bypassing locks or passwords

Auditors were responsible to identify threats that could occur, and that would be harmful to the firm's achievement of goals and objectives.

Components included communication circuits, network software, database files, terminals, processing units, and other devices. Examples included:

- Disaster recovery – procedures, components and information to put system back in operation, including disaster recovery plans, contingency plans, backup, off-site storage, secondary recovery sites, personnel, and other elements
- Facility – sites, buildings, and rooms housing system components, as well as drawings and specifications, environmental control devices, fire and flood mitigation mechanisms, health and safety codes, and physical security devices
- Hardware – computers, tape drives, disk drives, peripheral equipment, storage media, to include processing units, minicomputers, workstations, and PCs
- Information – data in system or components, to include files, applications, databases, transactions and reports
- Network – communication-related equipment and software, including circuits, modems, multiplexers, controllers, communication facilities, software, and security mechanisms
- Operations – personnel and processes to include manuals, documentation, physical and logical access management
- Software – programs to run and maintain the system, to include operating systems and applications software

Controls were procedures or physical items preventing threats from occurring or mitigating event impact.

1. Change and problem management – facilities, hardware, software, and communications networks
2. Cost/resource management – financial data
3. Disaster recovery tasks – documented and tested plan for off-site storage of backup data, alternative site provision, power, hardware, software, air conditioning, etc.
4. Environmental controls – fire, health and safety controls, temperature control, etc.
5. Hardware/software management – vendor support, maintenance plans, standards
6. Inventory controls – equipment and resource accountability

7. Performance goals and objectives – metrics such as resource utilization and lost time
8. Planning and forecasting – proper use of storage, to include planning for growth and upgrades
9. Policies and procedures – directives, codes, regulations, etc.
10. Process monitoring – process control and problem detection
11. Production controls – procedures for backup and recovery
12. Security – devices, techniques and software
13. Separation of functions – separation of duties to deny potential fraud or theft
14. Training and education – enhance job knowledge and security

The fourth step involved risk ranking both threats and components by each member of the auditing team, developing an ordinal list of threats and components. The most serious threat was placed first on the threat axis and the most important component placed at the top of the component axis. The cells were divided into High (top 25%), Medium (middle 50%), and Low (bottom 25%) categories, and colors applied to aid identification. Controls were then assigned to each cell.

As an example, threats could be ranked as follows by the auditing team, with lower numbers indicating more important threats:

1. Outages of system components
2. Unauthorized disclosure
3. Alteration of system
4. Errors and omissions
5. Excessive costs
6. Fraud or theft
7. System malfunction
8. Regulatory or contractual exposure
9. Denial of service

These threats were categorized by placing the first three in the high risk category, items ranked 4 through 6 in the medium risk category, and the last four in the low risk category.

Rankings for component importance could be:

1. Information
2. Hardware
3. Software
4. Network
5. Operations
6. Facility
7. Disaster recover

For each component, controls were assigned by risk category. As a possible example, ranks 1 and 2 might be categorized as critical, 3 and 4 as moderately

Table 2.8 IT risk matrix

	Threat low	Threat medium	Threat high
Criticality important	Amber	Red	Red
Criticality moderate	Green	Amber	Red
Criticality low	Green	Green	Amber

critical, and 5 through 7 as low in criticality. A risk matrix in line with what has been presented in this chapter could be as shown in Table 2.8.

This represents a conventional application of a risk matrix. Egerdahl went further, developing a matrix assigning specific control actions to each combination of threat and criticality, shown in the Appendix.

Conclusions

The study of risk management has grown in the last decade in response to serious incidences threatening trust in business operations. The field is evolving, but the first step is generally considered to be application of a systematic process, beginning with consideration of the organization's risk appetite. Then risks facing the organization need to be identified, controls generated, and review of the risk management process along with historical documentation and records for improvement of the process.

Risk matrices are a means to consider the risk components of threat severity and probability. They have been used in a number of contexts, basic applications of which were reviewed. Cox provided a useful critique of the use of risk matrices. A more detailed demonstration of risk matrices applied to information system technology based on the work of Egerdahl was presented.

Appendix: Controls Numbered as in Text

Threat	Component	1	2	3	4	5	6	7	8	9	10	11	12	13	14
System outage	Information	X	X	X	X	X		X	X					X	X
	Hardware	X	X	X	X	X		X						X	
	Software	X	X	X	X	X			X	X	X				X
	Network	X	X	X	X	X					X			X	X
	Operations				X			X			X			X	
	Facilities				X			X							
	Disaster recovery				X			X						X	
Unauthorized access	Information		X		X				X						X
	Hardware		X		X				X						X
	Software		X		X				X						X
	Network				X				X						
	Operations				X				X						

Threat	Component	1	2	3	4	5	6	7	8	9	10	11	12	13	14
	Facilities		X		X										
	Disaster recovery				X										X
System alteration	Information		X		X	X				X				X	X
	Hardware		X	X	X	X	X		X	X	X				X
	Software		X		X	X			X	X				X	X
	Network		X		X					X	X				X
	Operations		X									X			
	Facilities		X		X										
	Disaster recovery				X									X	X
Errors	Information		X		X	X				X				X	X
	Hardware		X	X	X	X	X		X	X	X				X
	Software		X		X	X			X	X				X	X
	Network		X		X					X	X				X
	Operations		X									X			
	Facilities		X		X										
	Disaster recovery				X									X	X
Excessive costs	Information		X				X					X			X
	Hardware	X	X			X	X			X		X			X
	Software		X	X		X				X		X			X
	Network		X	X											X
	Operations		X								X	X		X	X
	Facilities			X	X							X			
	Disaster recovery													X	
Fraud or theft	Information		X		X										X
	Hardware		X		X	X									X
	Software		X		X	X								X	X
	Network		X		X							X			
	Operations		X		X										X
	Facilities		X		X										
	Disaster recovery														
System malfunction	Information	X	X		X	X		X	X					X	X
	Hardware	X	X	X	X	X		X						X	
	Software	X	X	X	X	X			X	X	X				X
	Network	X	X	X	X	X					X			X	X
	Operations				X			X			X			X	
	Facilities				X			X						X	X
	Disaster recovery				X			X						X	
Legal exposure	Information		X												X
	Hardware		X	X		X									X
	Software		X	X		X				X					X
	Network			X				X							
	Operations		X												
	Facilities							X						X	X
	Disaster recovery		X												
Denial of service	Information		X		X										X
	Hardware		X												
	Software		X												X
	Network														
	Operations														
	Facilities														
	Disaster recovery														

Notes

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Chapter 3
Information Systems Security Risk

Security breaches to computer systems have consistently been a major drain on organizations, both private and public.[1] Providing information system security is challenged by environments containing evolving business requirements, with technology constantly being upgraded.[2] Vendors regularly have to send alerts to their clients. The computer security industry is rapidly growing in response to the concerns of those operating organizational computing systems. Threats arise externally and internally. External threats include attacks by organized criminals as well as potential threats from terrorists.[3] Internal threats are also present. Some problems arise due to turbulence in personnel, through new hires, transfers, and terminations. Most insider computer security incidents have been found to involve former employees.[4]

Keller et al. surveyed small businesses (less than 500 employees) in a Midwestern US city concerning computer security threats.[5] In the 1980s threats typically arose in the form of viruses affecting individual computers or networks. Viruses are computer codes designed to automatically spread across users, invading through disguise. A second generation of threats in the form of macro and e-mail viruses followed. Denial-of-service attacks became common in the 1990s. More recent threats arise in the form of worms (capable of self-replication to the point of slowing system performance) and Trojans (malicious code damaging systems once opened). Denial-of-services attacks block legitimate network access. Denial-of-service attacks of the 1990s have grown into network and global infrastructure attacks. They can take the forms of bandwidth consumption, resource starvation, or resource exploitation.[6] Flash attacks arise through cross-site scripting where code is inserted into web applications. Newer viruses have been developed to include viruses targeting instant messaging, voice-mail, mobile phones, and other personal devices.

Risks also exist in the form of spyware, adware, and malware downloaded from web sites without user knowledge. Spyware are programs residing on computers linked to the Internet that quietly collect information.[7] This has obvious risk in the exposure of personal information to users transacting business over the Web. It also can be a threat to supply chains through illegal transfer of proprietary information.

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Smith et al. gave six general categories of information technology risk[8]:

1. *Malicious code and programs*: This category includes *viruses*, *worms*, *Trojan horses* and *logic/time bombs*. These threats exist to all of us that use the Internet. While disseminators of these evil maladies continue to be creative in generating new threats, protection is available at the individual and system level.
2. *Malicious hacking and intrusion*: This threat can arise from unauthorized penetration of the system, for the purpose of obtaining illegal access to key information, or can involve denial of service attacks. Criminal forms include *password sniffing* to obtain access to bank or credit resources. There also have been many cases of industrial or government espionage. Business competitors have been known to deface Web sites.
3. *Fraud and deception*: Various forms of attacks in the form of *spoofing*, *masquerading*, or *salami attacks* have been used to do damage to privacy. Common electronic forms of fraud include *phishing* and credit card theft. Social engineering is often an effective means to obtain illegal access. Protection is best obtained through training, raising the level of awareness of employees and users, instilling an understanding of the need for sound password practices and other protective policies.
4. *Misuse and sabotage*: Resources can be misused, or vandalized through unauthorized access. One form is unauthorized software changes.
5. *Errors and omission*: Humans make errors, including software programmers. This category assumes accidental errors, to include unintended destruction of files or data, as well as routing or transmission errors. The category also includes programming errors.
6. *Physical and environmental hazards*: Nature throws many catastrophes at us, to include fires, floods, earthquakes, tsunamis and volcanic eruptions. Fellow humans can also disrupt service in both power as well as Internet (or intranet) access. Theft is another form of environmental hazard. Many highly publicized threats to identity on a massive scale arise from the theft of personal computers with sensitive information on them. Fortunately, thieves don't often realize the sensitive content that they have.

Despite these many threats from external sources, Keller et al. found that the majority of perceived threats from small businesses were due to internal causes, specifically personnel. Threats were perceived to arise from both intentional and accidental causes.

Definition

Information security is the preservation of information confidentiality, integrity, and availability. The aims of information security are to ensure business continuity, comply with legal requirements, and to provide the organization with a competitive edge (leading to profit in the private sector, more efficient administration in the public sector).

Frameworks

There are a number of best practice frameworks that have been presented to help organizations assess risks and implement controls. These include that of the international information security management standard ISO 17799, which facilitates planning, implementation and documentation of security controls.[9]

The ISO 17799 standards involve ten security domains[10]:

1. *Security policy* – statement of management commitment and support.
2. *Organizational security* – coordination and management of information security, and statement of responsibilities.
3. *Asset classification and control* – protection for critical or sensitive assets.
4. *Personnel security* – policies aimed to reduce risk of error, fraud, theft, or misuse of computer resources through training and increased awareness of risks and threats.
5. *Physical and environmental security* – prevention of unauthorized access and prevention of damage to information and facilities.
6. *Communications and operations management* – reduction of risk and consequences through proper and secure use of information processing facilities, and development of incidence response procedures.
7. *Access control* – protection of networked systems and detection of unauthorized activities.
8. *Systems development and maintenance* – prevention of loss, modification or misuse of information.
9. *Business continuity management* – development of the capacity to rapidly react to interruption of critical activities from any source.
10. *Compliance* – ensuring that laws and regulations are obeyed and respected.

Within each domain, specific procedures can be developed and recorded by each organization, outlining what is to be done to counteract risks and threats to information system security.

Other frameworks address how information security can be attained. Da Veiga and Eloff divided security governance into three divisions: strategic, managerial and operational, and technical.[11] Strategic factors involved leadership and governance. These involve sponsorship, strategy selection, IT governance, risk assessment, and measures to be used. Tudor identified functions of defining roles and responsibilities in this category.[12] The managerial and operational division includes organization and security policies and programs. This division includes risk management in the form of a security program, to include security culture awareness and training. Security policies manifest themselves in the form of policies, procedures, standards, guidelines, certification, and identification of best practices. The technical division includes programs for asset management, system development, and incident management, as well as plans for business continuity.

McCarthy and Campbell gave a Capability Maturity Model for information security that fits well within Tudor's security architecture and Da Veiga and

Eloff's security governance framework.[13] Capability maturity models give a set of security controls to protect information from unauthorized access, modification, or destruction. The seven levels give a nested set of elements to provide organizational information security:

- Level 1 – Security Leadership: strategy and metrics
- Level 2 – Security Program: structure, resources, and skill sets needed
- Level 3 – Security Policies: standards and procedures
- Level 4 – Security Management: monitoring procedures, to include privacy protection
- Level 5 – User Management: developing aware users and a security culture
- Level 6 – Information Asset Security: meta security, protection of the network and host
- Level 7 – Technology Protection and Continuity: protection of physical environment, to include continuity planning.

Information security faces many challenges, to include evolving business requirements, constant upgrades of technology, and threats from a variety of sources. Vendors and computer security firms send a steady stream of alerts about new threats arising from the Internet. Internally, new hires, transfers, and terminations may be the germination of threats from current or former employees. There also are many changes in legal requirements, especially for those organizations doing work involving the government.

Security Process

As a means to attain information technology security, Tracy proposed a series of steps[14]:

Establish a mentality: To be effective, the organization members have to buy in to operating securely. This includes sensible use of passwords. Those dealing with critical information probably need to change their passwords at least every 60 days, which may be burdensome, but provides protection for highly vulnerable information. Passwords themselves should be difficult to decipher, running counter to what most of us are inclined to use. Training is essential in inculcating a security climate within the organization.

Include security in business decision making: When software systems are developed, especially in-house, an information security manager should certify that organizational policies and procedures have been followed to protect organizational systems and data. When pricing products, required funding for security measures need to be included in business cases.

Establish and continuously assess the network: Security audits need to be conducted using testable metrics. These audits should identify lost productivity due to security failures, to include subsequent user awareness training.

Automation can be applied in many cases to accomplish essential risk compliance and assessment tasks. This can include vulnerability testing, as well as incident management and response. The benefits can include better use of information, lower cost of compliance, and more complete compliance with regulations such as Sarbanes-Oxley and HIPAA.

Within this general framework, Tracy gave a security process cycle, described in Table 3.1.

Table 3.1 Tracy's security process cycle[15]

Process	IT impact	Function
Inventory	Assets available	Access assets in hardware and software
Assess	Vulnerabilities	Automatically check systems for violations of risk policies based on regulatory and commercially accepted standards
Notify	Who needs to know?	Automatically alert those responsible for patch management, compliance
Remediate	Action needed	Automate security remediation by leveraging help desks, patch databases, configuration management tools
Validate	Did corrective actions work?	Automatically confirm that remediation is complete, record compliance and confirm compliance with risk posture policies
Report	Can you get information needed?	Give management views of enterprise IT risk and compliance, generate

This cycle emphasizes the ability to automate within an enterprise information system context.

Best Practices for Information System Security

Keller et al. gave nine best practices to protect against information system security threats[16]:

1. *Firewalls* – hardware or software, which block unallowed traffic. Firewalls do not protect against malicious traffic moving through legitimate communication channels. About 70% of security incidents have been reported to occur inside fire walls.
2. *Software updates* – application vulnerabilities are corrected by patches issued by the software source when detected. Not adopting patches has led to vulnerabilities that are commonly exploited by hackers.
3. *Anti-virus, worm and Trojan software* – should be installed on all machines. Management policies to reduce virus vulnerability include limiting shareware and Internet use, as well as user training and heightened awareness through education can supplement software protection.

4. *Password policy* – users face a constant tradeoff between sound password structure and workability (the ability to remember). But sound password use is needed to control access to authorized users. Human engineering in the form of naïve acquisition of passwords by intruders continues to be a problem.
5. *Physical security* – including disaster recovering planning and physical protection in the form of locks to control access to critical system equipment. Trash management also is important, as well as identification procedures.
6. *Policy and training* – because many information system security risks arise due to unawareness, a program of enlightenment can be very beneficial in controlling these risks. The other side of the coin is policy, the adoption of sound procedures governing the use of hardware, e-mail, and the Internet. Policy and training thus work together to accomplish a more secure system operating environment.
7. *Secure remote connections* – ubiquitous computing creates the opportunity to vastly expand mobile computing connections, and thus make workers much more productive. In order to gain these advantages, good encryption techniques are required as well as sound authentication procedures.
8. *Server lock down* – limiting server exposure is a basic principle. Those servers linking to the Internet need to be protected against intrusion.
9. *Intrusion detection* – systems are available to monitor network traffic to seek malicious bit patterns.

Supply Chain IT Risks

Information technology makes supply chains work through the communication needed to coordinate activities across organizations, often around the world.[17] These benefits require openness of systems across organizations. While techniques have been devised to provide the required level of security that enables us to do our banking on-line, and for global supply chains to exchange information expeditiously with confidence in the security of doing so, this only happens because of the ability of information systems staff to make data and information exchange secure.

IT support to supply chains involves a number of operational forms, to include vendor management inventory (VMI), collaborative planning forecasting and replenishment (CPFR), and others. These forms include varying levels of information system linkage across supply chain members, which have been heavily studied.[18]

Within supply chains, IT security incidents can arise from within the organization, within the supply chain network, or in the overall environment.[19] Within each threat origin, points of vulnerability can be identified and risk mitigation strategies customized. The greatest threat is loss of confidentiality. Smith et al. gave an example of a supplier losing their account when a Wal-Mart invoice was unintentionally sent to Costco with a lower price for items carried by both retailers. Supply chains require data integrity, as systems like MRP and ERP don't function without accurate data. Inventory information is notoriously difficult to maintain accurately.

Outsourcing

A major risk in information systems is outsourcing. Outsourcing provides many opportunities to operate at lower cost, improve quality of product or service, access the best available technology, accessing the open market around the world. Outsourcing those functions that are not an organization's core competencies allows them to focus on those core business activities that are. But outsourcing in IT involves many risks, sorted out by Faisal et al., with sources:

- Loss of control[20]
- Hidden costs[21]
- Disgreements, disputes, and litigation[22]
- Vendor opportunism[23]
- Information security exposure[24]
- Degradation of service[25]
- Poaching.[26]

Value Analysis in Information Systems Security

The value analysis procedure outlined earlier was used by Dhillon and Torkzadeh to sort objectives related to information systems security.[27] That process involved three steps, which they described as:

1. Interviews to elicit individual values.
2. Converting individual values and statements into a common format, generally in the form of object and preference. This step included clustering objectives into groups of two levels.
3. Classifying objectives as either fundamental to the decision context or as a means to achieve fundamental objectives.

Once the initial hierarchy was developed, it was validated by review with each of the seven experts involved. Subobjectives were then classified as essential, useful but not essential, or not necessary for the given decision context. Hierarchy clustering was also reviewed.

We will apply that hierarchy with the SMART procedure (also outlined earlier) to a hypothetical decision involving selection of an enterprise information (EIS, or ERP) system. Olson (2004b) reviewed tradeoffs among alternative forms of ERP in depth.[28] Olson also demonstrated the use of the SMART method in selecting from alternative forms of ERP.[29] The choices we consider are:

Alternative 1: A system obtained from a major vendor, without customization
Alternative 2: A system obtained from a major vendor that is customized
Alternative 3: Purchase of a smaller system from a vendor
Alternative 4: Engaging EIS through an application service provider (ASP)
Alternative 5: Do not obtain EIS

The tradeoffs among these systems are that using vendor software without customization (alternative 1) is the safest and fastest way to implement ERP, but is very expensive and locks client firms into the best practices designed by the vendor, which may force these clients to modify their business practices significantly, and gives them no competitive advantage over competitors who purchase the same vendor software. Customization of vendor software (alternative 2) gives client firms the opportunity to retain those business practices that they feel give them competitive advantage, but adds significantly to time and cost of installation, and is vulnerable to additional expense in future upgrades. There are at least three levels of ERP software being marketed. The first level includes SAP and Oracle (with subsidiaries), and is assumed for alternatives 1 and 2. At the second level, firms such as Microsoft have entered the market seeking to serve small-to-medium sized enterprises. Here we assume alternative 3 to be this second level of ERP. The third level involves more innovative firms, many open-sourced. This third level is not considered here. Alternative 4 is for the firm to rent a level 1 ERP from an application service provider. For purposes of comparison, the dummy alternative of doing nothing is included.

We will take Dhillon and Torkzadeh's value-focused hierarchy of criteria for information systems security risk, and select those elements that we think apply to the ERP selection decision.

Objective Hierarchy

Overall Objective: *Maximize IS Security*

The objective hierarchy consists of fundamental objectives, as well as means objectives. Dhillon and Torkzadeh gave a very good list of fundamental objectives related to information system security. Those that we feel relate to enterprise systems are highlighted in Table 3.2 in bold italics. Those that are not so highlighted are not material to the specific decision at hand, although they are important to overall information system security.

Table 3.2 Fundamental objectives related to information system security

Fundamental objective	Components
Enhance management development practices	Develop management team leading by example Ensuring individual computer literacy Increasing confidence in using computers Creating legitimate opportunities for financial gain Providing employees with adequate IT training ***Develop IT staff capabilities***

Table 3.2 (continued)

Fundamental objective	Components
Provide adequate human resource management practices	Provide necessary resources Create environment promoting contribution ***Encouraging high group morale*** Enhancing organizational pride Creating motivated environment Creating organizational code of ethics
Develop and sustain an ethical environment	Develop value system in organizational whistle blowing Develop coworker and organizational ethical relationships Instill value-based work ethics Instill professional work ethics Create environment promoting organizational loyalty Stress individuals treating each other as they want to be treated
Maximize access control	Create user passwords Provide several levels of user access Ensure physical security ***Minimize unauthorized access to information***
Promote individual work ethic	Maximize employee integrity in the company Minimize urgency of personal gain Create a desire to not jeopardize the company Create an environment promoting company profitability ***Minimize temptation to use information for personal benefit***
Maximize data integrity	***Minimize unauthorized changes*** ***Ensure data integrity***
Enhance integrity of business processes	Understand expected use of all available information Develop understanding of procedures and conduct codes ***Ensure appropriate organizational controls***
Maximizing privacy	***Emphasize importance of personal privacy*** ***Emphasize importance of rules against disclosure***
Maximize organizational integrity	Create environment of managerial support and solidarity Create environment of positive management interaction Create environment promoting respect Create environment promoting individual reliability Create environment of positive peer interaction

Many of these fundamental objectives do not relate to the domain of enterprise systems (Table 3.3).

We end up with a list of 22 criteria. The SMART method involves scoring each alternative on each of the criteria, with a score ranging from 0 (that alternative is as bad as can be imagined on that criterion) to 1 (that alternative is as good as can be imagined on that criterion). Table 3.4 shows the scores we assigned, reflecting our view of how well each alternative would be on each criterion.

Table 3.3 Means objectives related to information systems security

Means objective	Components
Increase trust	Display employer trust in employees Develop environment promoting organizational responsibility Maximize loyalty
Provide open communication	Minimize curiosity because of lack of information Create an open-door environment within all organizational levels ***Stress IT department interactiveness*** ***Develop open communication with the IT department*** Limit "arm's length" management
Maximize awareness	***Create an environment promoting awareness*** Develop awareness of balance between technical and social aspects of IS security Ensure explicit understanding of organizational culture by individuals Educate employee awareness about suspicious individuals and activities
Optimize work allocation practices	***Distribute workload optimally*** Monitor and adjust unoccupied time ***Develop understanding of organizational and information use procedures***
Establish ownership of information	Promote ownership in the organization Emphasize importance in confidentiality ***Emphasize understanding of the value of information*** Create a contract of confidentiality
Clarify centralization/ decentralization issues	***Ensure right balance between centralization/decentralization***
Ensure legal and procedural compliance	Minimize disregard for laws Decrease level of employer tolerance for misuse of information Develop understanding of legalities and regulations ***Develop mechanisms for information audit trail***
Improve authority structures	***Clarify delegation of authority*** Minimize the need to gain excessive control ***Link information access to individual positions***
Ensure availability of information	***Ensure adequate procedures for availability of correct information***
Promote responsibility and accountability	***Clarify delegation of responsibilities*** Maximize level of commitment to organization ***Create an environment promoting accountability***
Understand work situation	Minimize need to have leverage on others Minimize desire to seek revenge on others Minimize creation of disgruntled employees

Table 3.3 (continued)

Means objective	Components
Maximize fulfillment of personal needs	Appreciate personal needs for job enhancement Facilitate attainment of self-actualization needs
Understand individual characteristics	Understand particular individual characteristics and demographics to subvert controls Interpret individual lifestyles
Enhance understanding of personal financial situation	Understand the needs of different levels of financial status Eliminate the personal benefit of sharing information with competitors
Ensure censure	Introduce a fear of being exposed or ridiculed Instill a fear of consequences Instill a fear of losing your job Instill excommunication fear
Understand personal beliefs	Celebrate and understand the manner in which one was raised Minimize the need for greed in the organization Instill ethical and moral values

Table 3.4 Alternative scores on criteria

	Vendor	Custom	Small	ASP	No
Develop IT staff	1	0.8	0.4	0.1	0
Encourage group morale	0.5	0.8	0.4	0.3	1
Minimize unauthorized access	1	0.9	0.7	0.8	0.5
Minimize temptation to use information	1	0.9	0.9	1	0.3
Minimize unauthorized changes	1	1	1	1	0.2
Ensure data integrity	1	0.9	0.8	1	0.3
Ensure appropriate organizational controls	0.9	1	0.7	0.9	0.1
Emphasize importance of personal privacy	1	1	1	1	0.2
Emphasize rules against disclosure	1	0.9	1	1	0.3
Stress IT department interactiveness	1	1	1	1	0.2
Develop open communication with IT dept	1	1	1	1	0.3
Create an environment promoting awareness	1	1	1	1	0.3
Distribute workload optimally	1	0.9	0.7	1	0
Develop understanding of use procedures	0.7	1	0.8	0.7	0.6
Emphasize understanding of value of information	1	1	1	1	0.3
Ensure balance centralization/decentralization	0.8	1	0.6	1	0.2
Develop mechanisms for information audit trail	1	0.8	0.5	1	0
Clarify delegation of authority	1	1	0.6	1	0
Link information access to position	0.9	1	0.8	0.9	0.3
Ensure procedures for availability	0.7	1	0.6	0.7	0.1
Clarify delegation of responsibilities	1	0.9	0.7	1	0.4
Create environment of accountability	1	1	1	1	0.2

SMART Analysis

The next step of the SMART method is to develop relative weights (ranging from 0 to 1, with the sum equal to 1) for each criterion. Here we have 22 criteria, which is quite large (arguably larger than humans can reasonably compare at one time). The method to generate weights begins by sorting the criteria by relative importance. That criterion considered most important is assigned a value of 100, and each of the other criteria in turn assigned a relative score. Once all criteria are assigned scores, these scores are summed, and divided into each score to obtain relative weights with the property that they sum to 1.0. Table 3.5 shows the ranks, scores assigned, and subsequent criteria weights.

Table 3.5 SMART weight development

Criteria	Rank	Score	Weight
Ensure procedures for availability	1	100	0.139
Ensure appropriate organizational controls	2	95	0.132
Clarify delegation of responsibilities	3	90	0.126
Develop mechanisms for information audit trail	4	70	0.098
Minimize unauthorized changes	5	60	0.084
Ensure data integrity	5	60	0.084
Develop IT staff	7	50	0.070
Minimize unauthorized access	8	40	0.056
Ensure balance centralization/decentralization	9	35	0.049
Distribute workload optimally	10	25	0.035
Stress IT department interactiveness	11	20	0.028
Encourage group morale	12	10	0.014
Emphasize importance of personal privacy	12	10	0.014
Develop understanding of use procedures	12	10	0.014
Link information access to position	15	8	0.011
Develop open communication with IT dept	16	6	0.008
Emphasize understanding of value of information	16	6	0.008
Clarify delegation of authority	16	6	0.008
Create environment of accountability	16	6	0.008
Create an environment promoting awareness	20	5	0.007
Emphasize rules against disclosure	21	3	0.004
Minimize temptation to use information	22	2	0.003
		717	1.000

The last step of the SMART method is to apply these sets of weights in Table 3.5 to the matrix of alternative scores in Table 3.4. That yields value functions with respect to security that can be used to sort the alternatives. Here, by rank, we obtain:

1. Customized vendor system	Alternative 2	0.933
2. Vendor system without customization	Alternative 1	0.923
3. ASP	Alternative 4	0.856
4. Small system	Alternative 3	0.696
5. Do nothing	Alternative 5	0.202

Note that other factors need to be considered in the final selection of a system, to include cost, impact on organizational operations, training, implementation, and other factors. See Olson (2007) for elaboration.[30] Here we are using value analysis as a framework to identify factors important in information system security, and use SMART as a way to quantify those factors. This could become part of the overall hierarchy of all criteria needed to make the final selection decision among alternatives.

As can be seen, the analysis yielded a very close comparison between the first two alternatives. The relative tradeoffs are implicit from Table 3.4. They are elaborated in Table 3.6. The customized system has a relative advantage in employee morale, as they do not have to change their work methods as much, and here this alternative is given a slight advantage in ensuring organizational control (because methods are not changed as much as they would be with alternative 1). The customized system has an even stronger advantage in developing understanding of use procedures, as not as many procedures would be changed. Alternative 2 is also given credit for relative advantage in balancing centralization/decentralization, as organizational structure will be less likely to be modified than with alternative 1.

Table 3.6 Comparison of tradeoffs between alternative 1 and alternative 2

Criteria	Weight	Alt 1	Alt 2	Rationale
Ensure procedures for availability	0.139	0.7	1	Customizing existing processes has less disruption
Ensure appropriate organizational controls	0.132	0.9	1	Both provide organizational controls, but vendor system involves more change
Clarify delegation of responsibilities	0.126	1	0.9	Customized systems involve added complexity in responsibility assignment
Develop mechanisms for information audit train	0.098	1	0.8	Vendor systems are well designed for generic processes, customization confounds a bit
Ensure data integrity	0.084	1	0.9	Slight advantage to vendor system
Develop IT staff	0.070	1	0.8	IT staff have to implement the changes implied by customization
Minimize unauthorized access	0.056	1	0.9	Vendor systems are well designed for generic processes, customization confounds a bit
Ensure balance central/decent	0.049	0.8	1	Vendor systems change organizational processes, customization retains them
Distribute workload optimally	0.035	1	0.9	Vendor systems are well designed for generic processes, customization confounds a bit
Encourage group morale	0.014	0.5	0.8	Vendor systems disrupt existing practices; customization also disrupts, but much less

Table 3.6 (continued)

Criteria	Weight	Alt 1	Alt 2	Rationale
Develop understanding of use procedures	0.014	0.7	1	Vendor systems disrupt existing processes; customization retains best existing processes
Link information access to position	0.011	0.9	1	Both do well, but customization better fits existing links
Emphasize rules against disclosure	0.004	1	0.9	Vendor systems incorporate best practices, customization may introduce weaknesses
Minimize temptation to use information	0.003	1	0.9	Vendor systems incorporate best practices, customization may introduce weaknesses

In this case, the two top-scoring alternatives with respect to security are very close. They both have noticeable advantages over the other alternatives considered. The ASP option is very weak with respect to developing IT staff (they would for the most part be released from employment), and encouraging group morale (release of colleagues from employment is expected to be detrimental to morale). Otherwise, the ASP option does well on security matters. The smaller system scores relatively weaker on over half of the criteria considered, indicating security issues more severe than the ASP. All four of these enterprise system options are expected to improve the preexisting security situation.

Conclusion

Information systems security is critically important to organizations, private and public. We need the Internet to contact the world, and have benefited personally and economically from using the Web. But there have been many risks that have been identified in the open Internet environment.

A number of frameworks have been proposed. Some appear in the form of standards, such as from the International Standards Organization. That set of standards provides guidance in the macro-management of information systems security. Frameworks can provide guidance in developing processes to attain IS security, to include Tracy's Security Process Cycle and Keller et al.'s best practices.

Supply chains are an especially important economic use of the Internet, and involve a special set of risks. While there are many inherent risks in electronic data interchange (needed to efficiently manage supply chains), methods have been developed to make this a secure activity in well-managed supply chains.

One way that many organizations deal with information systems is to outsource, hiring experts with strong software to do their information processing. This can be a very cost-effective means, especially for those organizations who feel that their core competencies do not include information technology (or at least all aspects of IT). Outsourcing does involve risks, which were outlined by Faisal et al.

To more thoroughly evaluate information systems security, Dhillon and Torkzadeh proposed value analysis. Value analysis provides a valuable means of identifying factors of general importance. Each particular decision would be able to filter this rather long list down to those issues of importance in a particular context. Here we suggest value analysis as a means to focus on the impact of information systems security factors on alternative forms of enterprise information systems. We then demonstrated how the process, combined with SMART analysis, can be used to identify the relative importance of factors, and provide a framework to more thoroughly analyze tradeoffs among alternatives.

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Chapter 4
Enterprise Risk Management in Projects

Project management inherently involves high levels of risk, because projects by definition are being done for the first time. There are a number of classical project domain types, each with their own characteristics. For instance, construction projects focus on inanimate objects, such as materials that are transformed into some purposeful object. There are people involved, although as time passes, more and more work is done by machinery, with diminishing human control. Thus construction projects are among the more predictable project domains. Government projects often involve construction, but extend beyond that to processes, such as the generation of nuclear material, or more recently, the processing of nuclear wastes. Government projects involve high levels of bureaucracy, and the only aspect increasing predictability is that overlapping bureaucratic involvement of many agencies almost ensures long time frames with high levels of change. There is a very wide spectrum of governmental projects and therefore they can't be generalized, but they can include large scale procurement as found in military administration, emergency response,[1] and social programs. They also should include civil works, which drive most construction projects. A third project domain is information system project management, focusing on the development of software tools to do whatever humans want. This field, like construction and governmental projects, has been widely studied. It is found to involve higher levels of uncertainty than construction projects, because software programming is a precise activity, and getting a computer code to work without bugs is a precise activity.

Seyedhoseini et al.[2] reviewed risk management processes within projects, using the contexts of general project management, civil engineering, software engineering, and public application. Those authors looked at 16 risk management processes published over the period 1990–2005, spread fairly evenly over their four context areas, identifying methodologies. These contexts all involve basic project management, but we argue that each context is quite different. Project management in civil engineering is usually easier to manage, as the uncertain elements involve natural science (geology, weather). However, there are many different types of risk involved in any project, to include political aspects[3] and financial aspects.[4] While these sources provide more than enough uncertainty for project managers, there is a much more difficult task facing software engineering project managers.[5] We argue that

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this is because people are more fundamental to the software engineering production process, in the form of developing systems, programming them, and testing them, each activity involving high degrees of uncertainty.[6] Public application projects are also unique unto themselves, with high levels of bureaucratic process that take very long periods of time as the wheels of bureaucracy grind slowly and thoroughly. Slowly enough that political support often shifts before a project is completed, and thoroughly enough that opposition of the “not-in-my-backyard” is almost inevitably uncovered prior to project completion.

Project Management Risk

The Project Management Institute views risk as general to projects, and through the Project Management Body of Knowledge (PMBOK),[7] which consists of a checklist of project management elements by topic. Risk management is a major element of PMBOK, with major categories of:

- planning,
- risk identification,
- quantitative risk analysis,
- quantitative risk analysis,
- risk response planning, and
- risk monitoring and control.

The Project Risk Analysis and Management (PRAM) Guide in the United Kingdom is very similar in approach,[8] and fits the description of a typical risk management program from other sources. Each of these categories applies to all projects to some degree, although the level of uncertainty can make variants of tools applied appropriate. A number of recent papers have proposed risk assessment methodologies in construction, based on an iterative process of risk identification, risk analysis and evaluation, risk response development, and administration.[9] The key is to keep systematic records over time to record risk experiences, with systematic updating.[10]

Risk Management Planning

As with any process, inputs need to be gathered to organize development of a cohesive plan. Things such as the project purpose and stakeholders need to be identified, followed by identification of tasks to be accomplished. This applies to every kind of project. These tasks are cohesive activities, usually accomplished by a specific individual or group, and for each task estimation of duration and resources required, as well as immediate predecessor activities is needed. This is the input needed for critical path analysis, to be demonstrated in this chapter. That quantitative approach deals with risk in the form of probability distributions for durations (demonstrated in this chapter through simulation).

But there are other risk aspects that need to be considered. It is important to consider the organization's attitude toward risk, and qualitatively identify things that can go wrong. Risk attitude depends upon stakeholders. Identification of what might go wrong and stakeholder preference for dealing with them can affect project management team roles and responsibilities.

Risk management planning concludes with a risk management plan. This plan should define methodologies for dealing with project risks. Such methodologies can include training internal staff, outsourcing activities that other organizations are better equipped to deal with, or insurance in various forms. Ultimately, every organization has to decide which risks they are competent to manage internally (core competencies), and which risks they should offload (at some expected cost).

Risk Identification

Once the risk management plan is developed, it can naturally lead to the next step, risk identification. The process of risk identification identifies major potential sources of risk for the specific project. The risk management plan identifies tasks with their risks, as well as project team roles and responsibilities. Historical experience should provide guides (usually implemented in the form of checklists) to things that can go wrong, as well as the organization's ability to cope with them.

Specific types of risk can be viewed as arising in various ways. A classical view is the triumvirate of quality, time, and budget. Software projects are often said to allow any two of the three – you can get code functioning as intended on time, but it usually involves more cost than expected; you can get functional code within budget as long as you are patient; you can get code on time and within budget as long as you don't expect it to work as designed. This software engineering project view often generalizes to other projects, but with some different tendencies. In construction, there is less duration variance, although unexpected delays from geology or the weather commonly create challenges for project managers. If weather delays are encountered, the tradeoff is usually whether to wait for better weather, or to pay more overtime or extra resources. If geological elements are creating difficulties, more time and money is usually required. The functionality of the project is usually not degraded. Governmental projects may involve emergency response, where time is not something that can be sacrificed. The tradeoff is between quality of response and cost. Usually emergency response teams do the best they can within available resources, and public outcry almost always criticizes the insufficiency of the effort.

There are a number of techniques that can be used to identify risks. Some qualitative approaches include interviews of experts or stakeholders, supplemented by techniques such as brainstorming, the nominal group technique, the Delphi method, or SWOT analysis (strengths, weaknesses, opportunities, and threats). Each of these methods are relatively easy to implement, and the quality of output depends on the participation of a diverse group of stakeholders. Historical data can also be used if the organization has experience with past projects similar to the current activity. This works well if past experiences are well-documented and retrieved efficiently.

The outputs from risk identification is a more complete list of risks expected in the project, as well as possible responses along with their expected costs. This results in a set of responses that can be reviewed as events develop, allowing project managers to more intelligently select appropriate responses. While success can never be guaranteed, it is expected that organizational project performance will improve.

Qualitative Risk Analysis

After a more precise estimation of project element risk is identified, the relative probabilities and risk consequences can be addressed. Initial estimations usually require reliance on subjective expert opinion. Historical records enable more precision, but one project element of importance is that projects by definition almost always involve new situations and activities. Experts have to judge the applicability of historical records to current challenges.

A qualitative risk analysis can be used to rank overall risks to the organization. A priority system can be used to identify those risks that are most critical, and thus require the greatest degree of managerial attention. In critical path analysis terms, critical path activities would seem to call for the greatest managerial attention. Behaviorally, humans tend to work hardest when the boss is watching. However, the fallacy of this approach is that other activities that are not watched may become critical too if they delay too far beyond their expected duration.

Qualitative risk analysis can provide a valuable screening to cancel projects that are just too risky for an organization. It also can affect project organization, with more skilled personnel assigned to tasks that call for more careful management. It also can be a guide to look for means to offload risk, either through subcontracting, outsourcing, or insurance.

Quantitative Risk Analysis

We will present more formal quantitative tools in the following sections. Quantitative analysis requires data. The critical path method calls for a specific duration estimate, which we will demonstrate. Simulation is less restrictive, calling for probability distributions. But this is often more difficult for humans to estimate, and usually only works when there is some sort of historical data available with which to estimate probability distributions.

Quantitative risk analysis, as will be demonstrated, can be used to estimate probabilities of project completion times, as well as other items of interest that can be included in what is essentially a spreadsheet model. These examples focus on time. It is also possible to include cost probabilities.

Risk Response Planning

Once risk analysis (qualitative, quantitative, or both) is conducted, project managers are hopefully in a more educated position to make plans and decisions to respond to events. Risk response planning is this process of developing options and reducing threats if possible. The severity of risks as well as cost, time, and impact on project output (quality) should be considered.

A broad categorization of risk treatment strategies include:

- Risk avoidance (adopting alternatives that do not include the risk at issue)
- Risk probability reduction (act to reduce the probability of adverse event occurance)
- Risk impact reduction (act to reduce the severity of the risk)
- Risk transfer (outsourcing)
- Risk transfer (insurance)
- Add buffers to the project schedule

The process of project risk management is for project decision makers to tradeoff the costs of each risk avoidance strategy in light of organizational goals. The key to success is for organizations to adopt those risks internally where they have competency in dealing with the risk at issue, and to pay some price to offload those risks outside of their core competencies.

The output of risk response planning can be a prioritized list of risks with potential responses. It also can include assignment of specific individual responsibilities for monitoring events and triggering planned responses.

Risk Monitoring and Control

This category of activity is implementation of all prior categories. Accounting is the first line of measurement of cost activity. Operational project management personnel also need to keep on top of time and quality performance as the project proceeds. When adverse events are identified, corrective action (either adoption of contingency plans, or development of alternative actions) need to be applied. In the long run, it is important to document projects, both in terms of specific time and cost experiences, as well a qualitative case data to enable the organization to do better on future projects.

Project Management Tools

A variety of risk management implementation tools have been applied. We referred to PMBOK earlier, which is intended to provide a process model to generic risk management projects. There are other process models, to include the Software Engineering Institute's capability maturity model (CMM). The five levels of the CMMI are shown in Table 4.1.

Table 4.1 Capability maturity model for software engineering processes

Level	Features	Key processes
1. Initial	Chaos	Survival
2. Repeatable	Individual control	Software configuration management Software quality assurance Software subcontract management Software project tracking and oversight Software project planning Requirements management
3. Defined	Institutionalized process	Peer reviews Intergroup coordination Software product engineering Integrated software management Training program Organization process definition Organization process focus
4. Managed	Process measured	Quality management Process measurement and analysis
5. Optimizing	Feedback for improvement	Process change management Technology innovation Defect prevention

Source: Olson (2004a).

The CMM level 1 covers software engineering organizations that do nothing. The other four levels involve distinctly different process areas, leading to better control over software development. It should be noted that attaining each level involves an organizational cost in added bureaucracy, which requires a business decision on the part of each organization. However, there is a great deal of research that indicates that in the long run, software quality is improved dramatically by moving from any level to the next higher level, and that overall development cost and development time are improved. This is a clear example of risk management – paying the price of more formality to yield reduced risk in terms of product output. Other process risk management models in software engineering include Boehm's spiral model,[11] which provides iterative risk analysis throughout the phases of the software development.

Bannerman[12] categorized software project risk management into the three areas of process models (reviewed above), analytical frameworks (based on some dimension such as risk source, the project life cycle, or model elements), and checklists.

Checklists are often found as the means to implement risk management, with evidence of positive value.[13] Checklists can be (and have been) applied in any type of project. To work well, the project must repeat a domain, as each type of project faces its own list of specific risks. The value of a checklist of course improves with the depth of experience upon which it is based.

Simulation Models of Project Management Risk

We will focus on demonstrating quantitative tools to project risk management. We will demonstrate how simulation can be used to evaluate the time aspect of project management risk. The models are based on critical path, which can be modeled in Excel, enabling the use of distributions through Crystal Ball simulation. We begin with a basic software engineering project using a traditional waterfall model. Figure 4.1 gives a schematic of the activities and their precedence relationships.

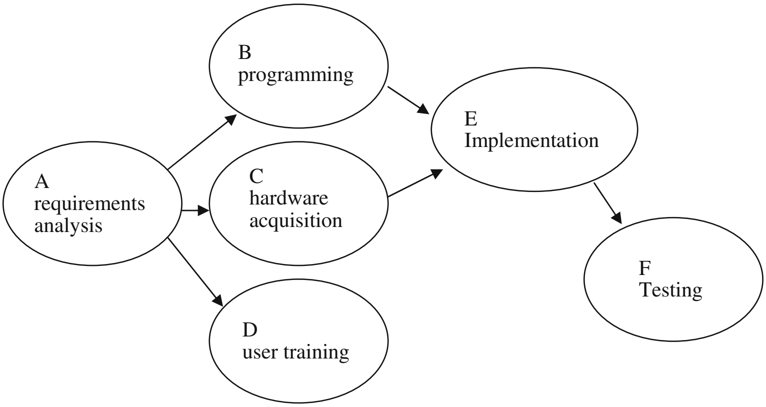
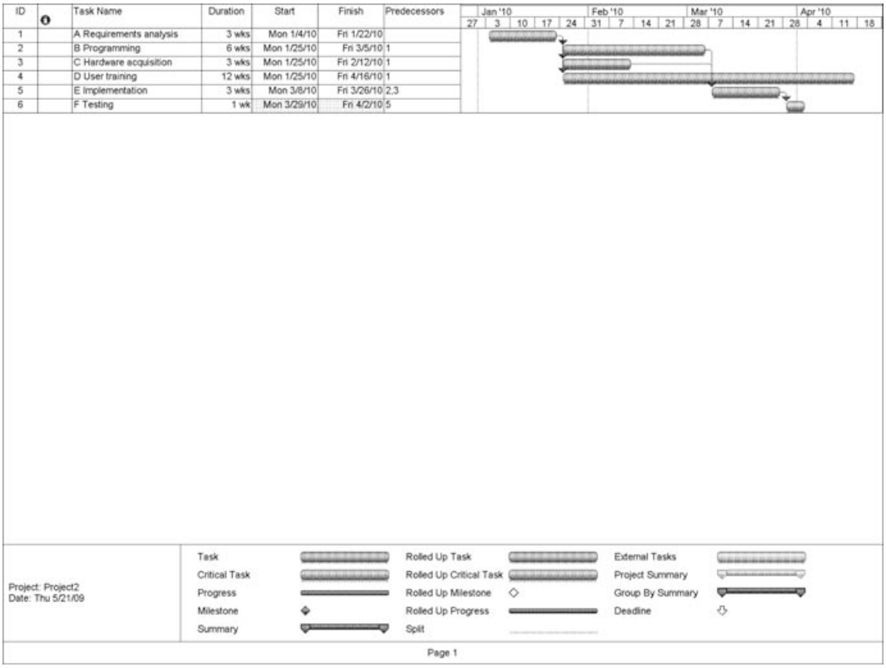


Fig. 4.1 Network for software installation example

Table 4.2 gives the input information, along with distributions assumed for each activity. These distributions should be based on historical data if possible, subjective expert judgment if historical data is not available.

Table 4.2 Software installation input data

Activity	Duration	Distribution	Predecessors
A. Requirements analysis	3 weeks	Normal (3,0.3)	None
B. Programming	7 weeks	Lognormal (7,1)	A
C. Hardware acquisition	3 weeks	Normal (3,0.5)	A
D. User training	12 weeks	Constant	A
E. Implementation	5 weeks	Exponential (5)	B,C
F. Testing	1 week	Exponential (1)	E



ID		Task Name	Duration	Start	Finish	Predecessors
1		A Requirements analysis	3 wks	Mon 1/4/10	Fri 1/22/10	
2		B Programming	6 wks	Mon 1/25/10	Fri 3/5/10	1
3		C Hardware acquisition	3 wks	Mon 1/25/10	Fri 2/12/10	1
4		D User training	12 wks	Mon 1/25/10	Fri 4/16/10	1
5		E Implementation	3 wks	Mon 3/8/10	Fri 3/26/10	2,3
6		F Testing	1 wk	Mon 3/29/10	Fri 4/2/10	5

Project: Project2
Date: Thu 5/21/09

Page 1

Fig. 4.2 Microsoft project model output

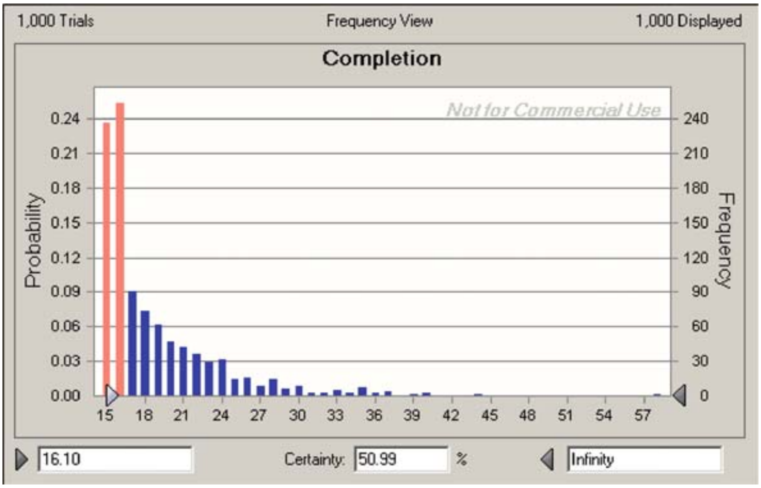
Figure 4.2 gives the Microsoft Project output for this model.

The Excel model based on critical path analysis is given in Table 4.3.

Some modeling adjustments were needed. For all distributions, durations in weeks were rounded up in the Duration column of Table 4.1. For normal distributions, a minimum of 0 was imposed. Note that the lognormal distribution in Crystal Ball requires a shape parameter (constrained to be less than the mean). Here the

Table 4.3 Crystal ball model of software installation project

Activity	Distribution	Duration	Start	Finish
A. Requirements analysis	=CB.Normal(3,0.3)	=INT(MAX(0,B2)+0.99)	=0	=D2+C2
B. Programming	=CB.Lognormal(5,7,1)	=INT(B3+0.99)	=E2	=D3+C3
C. Hardware acquisition	=CB.Normal(3,0.5)	=INT(MAX(0,C2)+0.99)	=E2	=D4+C4
D. User training	12	=B5	=E2	=D5+C5
E. Implementation	=CB.Exponential(0.2)	=INT(B6+0.99)	=MAX (E3,E4)	=D6+C6
F. Testing	=CB.Exponential(1)	=INT(B7+0.99)	=E6	=D7+C7
				=MAX (E2:E7)



16.10

Certainty: 50.99 %

Infinity

Fig. 4.3 Simulated software installation completion time

shape parameter is 5, the mean 7, and standard deviation 1. Also note that the exponential distribution's mean is inverted, so for E Implementation, 5 weeks becomes 0.2. Figure 4.3 gives the simulation results (based on 1,000 replications).

The average for this data was 18.62 weeks, compared to the critical path analysis 16 weeks (which was based on assumed duration certainty). There was a minimum of 15 weeks (0.236 probability) and a maximum of 58 weeks. There was a 0.490 probability of exceeding 16 weeks.

There are other simulation systems used for project management. Process simulation allows contingent sequences of activities, as used in the Project Assessment by Simulation Technique (PAST).[14]

Governmental Project

We assume a very long term project to dispose of nuclear waste, with activities, durations and predecessor relationships given in Table 4.4 (Figs. 4.4 and 4.5).

Table 4.5 gives the Excel (Crystal Ball) model for this scheduling project. Normal distributions were used for project manager controllable activities, and lognormal distributions used for activities beyond project manager control.

Minimum completion time based on 1,000 replications was 280 months, and maximum 391 months (Fig. 4.6). The mean was 332 months, with a standard deviation of 16 months. The distribution of completion times appears close to normal. Table 4.6 gives the probabilities of completion in 10-month intervals:

Table 4.4 Nuclear waste disposal project

Activity	Duration	Distribution	Predecessors
A. Decision staffed	60 weeks		None
B. EIS	70 weeks		A
C. Licensing study	60 weeks		A
D. NRC	30 weeks		A
E. Conceptual design	36 weeks		A
F. Regulation compliance	70 weeks		E
G. Site selection	40 weeks		A
H. Construction permit	0	Constant	D,F,G
I. Construction	100 weeks		H
J. Procurement	70 weeks		F SS, I SS+5 weeks
K. Install equipment	72 weeks		I
L. Operating permit	0		K
M. Cold start test	16 weeks		K
N. Readiness test	36 weeks		M
O. Hot test	16 weeks		N
P. Begin conversion	0		L,O

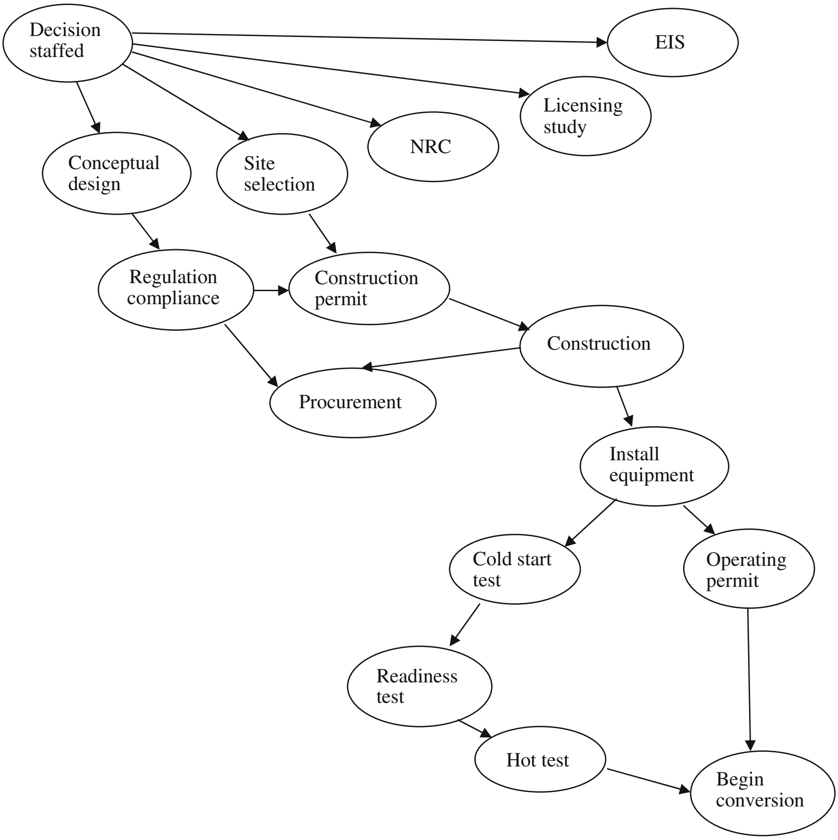
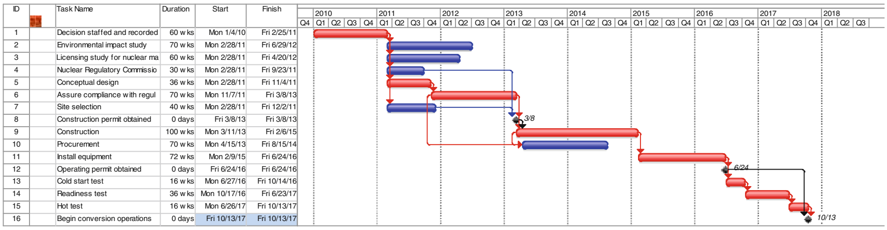


Fig. 4.4 Network for governmental project



ID		Task Name	Duration	Start	Finish
1		Decision staffed and recorded	60 w ks	Mon 1/4/10	Fri 2/25/11
2		Environmental impact study	70 w ks	Mon 2/28/11	Fri 6/29/12
3		Licensing study for nuclear ma	60 w ks	Mon 2/28/11	Fri 4/20/12
4		Nuclear Regulatory Commissio	30 w ks	Mon 2/28/11	Fri 9/23/11
5		Conceptual design	36 w ks	Mon 2/28/11	Fri 11/4/11
6		Assure compliance with regul	70 w ks	Mon 11/7/11	Fri 3/8/13
7		Site selection	40 w ks	Mon 2/28/11	Fri 12/2/11
8		Construction permit obtained	0 days	Fri 3/8/13	Fri 3/8/13
9		Construction	100 w ks	Mon 3/11/13	Fri 2/6/15
10		Procurement	70 w ks	Mon 4/15/13	Fri 8/15/14
11		Install equipment	72 w ks	Mon 2/9/15	Fri 6/24/16
12		Operating permit obtained	0 days	Fri 6/24/16	Fri 6/24/16
13		Cold start test	16 w ks	Mon 6/27/16	Fri 10/14/16
14		Readiness test	36 w ks	Mon 10/17/16	Fri 6/23/17
15		Hot test	16 w ks	Mon 6/26/17	Fri 10/13/17
16		Begin conversion operations	0 days	Fri 10/13/17	Fri 10/13/17

Fig. 4.5 Gantt chart for governmental project

Table 4.5 Model for governmental project

	A	B	C	D	E
1	Activity	Duration		Start	End
2	A. Decision staffed	=INT (CB.Normal(60,5))	None	0	=D2+B2
3	B. EIS	=INT (CB.Lognormal(70,10))	A	=E2	=D3+B3
4	C. Licensing study	=INT (CB.Lognormal(60,10))	A	=E2	=D4+B4
5	D. NRC	=INT (CB.Lognormal(30,5))	A	=E2	=D5+B5
6	E. Conceptual design	=INT (CB.Normal(36,6))	A	=E2	=D6+B6
7	F. Regulation compliance	=INT (CB.Normal(70,10))	E	=E6	=D7+B7
8	G. Site selection	=INT (CB.Normal(40,5))	A	=E2	=D8+B8
9	H. Construction permit	=0	D,F,G	=MAX (D5,D7,D8)	=D9+B9
10	I. Construction	=INT (CB.Lognormal(100,10))	H	=D9	=D10+B10
11	J. Procurement	=INT (CB.Normal(70,5))	F SS, I SS+5 weeks	=MAX (D7,D10+5)	=D11+B11
12	K. Install equipment	=INT (CB.Normal(72,5))	I	=E10	=D12+B12
13	L. Operating permit	=0	K	=E12	=D13+B13
14	M. Cold start test	=INT (CB.Lognormal(16,6))	K	=E12	=D14+B14
15	N. Readiness test	=INT (CB.Lognormal(36,6))	M	=E14	=D15+B15
16	O. Hot test	=INT (CB.Lognormal(16,6))	N	=E15	=D16+B16

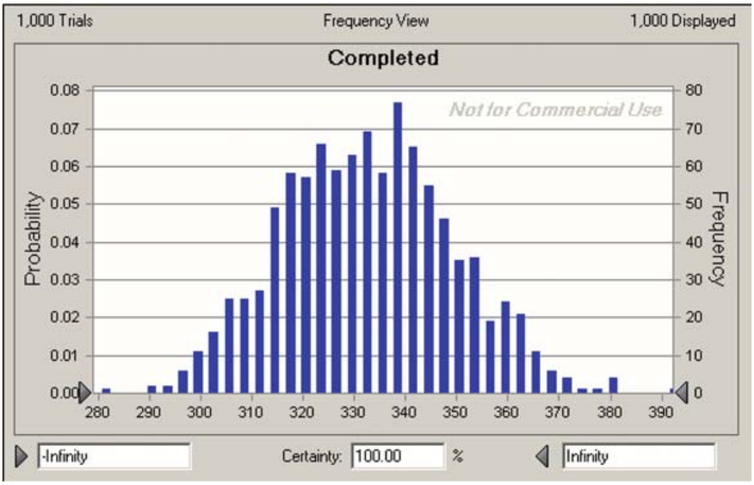


Fig. 4.6 Histogram of governmental project completion time in months

Table 4.6 Probability of completion

Months	Probability
310	0.912
320	0.759
330	0.550
340	0.329
350	0.153
360	0.057
370	0.011
380	0.005

Conclusions

We have argued that there are a number of distinct project types, to include more predictable projects such as those encountered in civil engineering, highly unpredictable projects such as encountered in software engineering, and projects involving massive undertakings or emergency response typically faced by government bureaucracies. There are many other types of projects, of course. For instance, we did not discuss military procurement projects, which are extremely important unto themselves. This type of project is a specific kind of governmental project, but here we focused more on emergency management (which military operations is closer to).

We also presented a framework for project risk analysis, based on PMBOK. This included a number of qualitative elements which can be extremely valuable in project management. But they are less concrete, and therefore we found it easier to focus on quantitative tools. We want to point out that qualitative tools are also very important.

The qualitative tools presented start with the deterministic critical path method, which assumes no risk in duration nor in resource availability. We present simulation as a very useful means to quantify project duration risk. Simulation allows any kind of assumption, and could also incorporate some aspects of resource availability risk through spreadsheet models.

While the ability to assess the relative probability of risk is valuable, the element of subjectivity should always be kept in mind. A simulation model can assign a probability of any degree of precision imaginable, but such probabilities are only as accurate as the model inputs. These probabilities should be viewed as subject to a great deal of error. However, they provide project managers with initial tools for identification of the degree of risk associated with various project tasks.

Notes

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Chapter 5
Natural Disaster Risk Management

Risks can be viewed as threats, but business exists to cope with risks.[1] Different disciplines have different ways of classifying risks. In finance, in order to explain the risk management lessons from the Credit Crisis, Jorion classified risks into: known knowns, known unknowns and unknown unknowns.[2] To focus on natural disaster risk management, we propose the following general way to classify risks: Field based and Property based.

- Field based classification

  Financial risks, which basically includes all sorts of risks related to financial sectors and financial aspects in other sectors; these are, but not restricted to, market risk, credit risk, operational risk, operational risk, liquidity risk.

  Nonfinancial risks, which includes risks from sources that are not related to finance. These include, but are not restricted to, political risks, reputational risks, bioengineering risks, and disaster risks.
- Property based classification

We think risks can have five properties: uncertainty, dynamics, dependence, clustering and complexity. We define the first two (uncertainty, dynamics) as individual characteristics and the next two (dependence, clustering) as group characteristics. The first two properties, i.e., uncertainty and dynamics have been widely recognized in inter-temporal models from behavioral decision making and behavioral economics.[3] The next two properties, i.e., dependence and clustering are well studied in the finance discipline. For example, in finance, volatility clustering has been observed in many markets by referring to the observation that "large changes tend to be followed by large changes, of either sign, and small changes tend to be followed by small changes." The characteristics of complexity mainly indicate that individual characteristics can evolve into group characteristics and vice versa.

Uncertainty of risks reflects uncertain severity and uncertain probability for adverse event to take place. Uncertainty of risks proposes the utilization of probability theory and various distributions to model risks. This can be dated back to 1700s where Bernoulli, Poisson, Gauss modeled normal events and

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general Pareto distributions and general extreme value distribution were used to model extreme events.

Dynamics of risks reflects timing effects, where risks change as time spans. Dynamics of risks proposes using stochastic process theory in risk management. This can be dated back to 1930s where Markov processes, Brownian motion and Levy processes were developed.

Dependence and clustering of risks mainly deals with correlation and clustering effects among risk factors. Various Copula functions are built and Fourier transformations are also used here. This has been a newer area of research since 1950s.

Complexity of risks relies on the theory of complexity science, which evolves from system science theory and cybernetics. Complexity science research has been developed very rapidly since 1960s.

Emergency Risk Management in China

China has developed into a global economic power to rival that of America and Japan and there are few multinational companies that are not sourcing, selling or manufacturing in China. Most Fortune 500 companies have a presence in China and the list includes 35 Chinese companies in 2007. Chinese companies are also investing abroad. China remains the world’s most exciting place to do business and understanding how to do business efficiently there is the key to corporate growth strategy. In China’s rapidly evolving economy, managers are increasingly faced with environments characterised by high levels of uncertainty and change. These uncertain and changing environments bring about risk that can arise from internal or external sources, and includes exposure from economic or financial loss or gain, property damage, failure of meeting strategic objectives, unfavourable reputation, breach of OHS requirements, mismanagement, or technology failure. The organisational challenges that ensue require managers to possess the necessary risk management skills, knowledge and capacities at all levels. Risk exposures represent potential losses to the organisation that can either be mitigated or unmitigated. The Chinese public sector is increasingly involved in addressing overall strategic resource management during natural event disaster at both macro- and micro-level risk management in a volatile commercial environment. Due to the general lack of well functioning local insurance markets, many developing countries rely on funding sources such as charities, foreign and local governments to assist in the recovery and rehabilitation process, further reducing incentives to engage in prevention and insurance. Moreover, local government recovery financing requirements divert funds from public capital budgets and disrupt long-term development investments.

China is a collection of regions to better understand the development, regulation and social structures. China is also prone to natural disasters such as earthquakes and floods. Kleindorfer and Kunreuther suggest that economic assets are increasingly being built in exposed regions.[4] This situation increases the potential damage of natural catastrophes posing a real challenge to government and firms in terms of resource allocation for disaster rehabilitation and recovery. A case in point is the recent Sichuan earthquake during which massive civil and military resources were diverted to help in the rescue, recovery and reconstruction operations. The Tangshan earthquake in 1978 killed more than 300,000 people and 90,000 in Szechuan recently. Thus, the risk exposure in China varies for different regions due to these factors. Individual province has its own characteristics in relation to business and catastrophe risk exposure. When natural catastrophes occur the results are significant economic losses and human casualties. The levels of casualties and economic loss from these events are the result of a combination of the severity of the catastrophe, the development of the environment and population density. Furthermore, the presence and amount of investment exposure of a firm in a disaster area are also factors that have a financial impact on the firm. Generally, firms do not adequately address the disaster risk that can compromise operational and financial sustainability. The aim of this paper is to highlight the financial issues relating to managing catastrophic risk due to the increasing gap in financial disaster losses as evident from the recent Szechuan earthquake. The analysis is conducted from the perspective of sustaining a firm's value through financial and operational risk management in a natural disaster prone region.

The development of disaster-related corporate policies is largely focused on crisis or emergency response, without a formal ex-ante evaluation and mitigation of the natural disaster hazards. Many governments of developing countries and firms operating in these countries do not take precautionary measures to mitigate the impact of disasters and the local insurance markets are usually unable to meet the risk financing requirements satisfactorily. Given this situation, we analyse and discuss the alternative risk transfer mechanisms and corporate operating structures to mitigate catastrophe risk exposure. This paper focuses on the risk mitigation of natural disaster hazards in a financial context by analysing the organisational risk management measures and financial instruments for mitigating disaster risk. In essence, the effectiveness of disaster risk management will depend on the mix of available organizational and market-based mechanisms.

Natural Disaster and Financial Risk Management

Risk is the probability of an adverse event occurring with the potential to result in loss to exposed element. Natural hazards are meteorological or geological phenomena that due to their location, frequency, and severity, have the potential to affect economic activities. A natural event that results in human and economic losses is an environmental problem contributed by the development in the region. The Szechuan earthquake shows that businesses cannot avoid disaster risk and a single catastrophic event can wipe out years of achievements. Natural catastrophe risk is generally characterized by low frequency and high severity, though the level of severity varies quite significantly. The extent of the development contributes to the financial vulnerability to the catastrophic effects of the natural disaster. On the same token, the vulnerability of a firm from hazard events depends on the size of its investment and revenue exposures in the region. China's huge population and limited habitable land mean that there is a higher density of people and economic development in regions exposed to natural hazards. Natural hazards can be characterized by location, timing, magnitude and duration. The principal causes of vulnerability include imprudent investments and ineffective public policies.

Natural disaster losses are the result of mismanaged and unmanaged disaster risks that reflect current conditions and historical factors.[5] According to Cardon, disaster risk exposure comes from the interaction between a natural hazard (the external risk factor) and vulnerability (the internal risk factor).[6] Proactive disaster risk management requires a comprehensive process that encompasses a comprehensive pre-disaster evaluation involving the three broad steps involving the following activities:

- identification of the potential natural hazards and evaluation of investment at risk;
- risk reduction measures to address the vulnerability, and
- risk transfer to minimise financial losses.

The need to integrate disaster risk management into investment strategy is necessary to manage corporate value and reduce risk in the future. These should be supported by effective governance (e.g. policies, planning, etc), supplemented by effective information and knowledge sharing mechanisms among different stakeholders.

First, risk identification involves creating an awareness and quantification of risk through understanding vulnerabilities and exposure patterns. The process also includes analysis of the risk elements and the underlying causes of the exposure. This knowledge is essential for development of strategies and measures for risk reduction. For example, firms operating in an earthquake-prone zone would need to keep abreast of information on real-time seismic patterns complemented with forecasts on expected hazards. This is complemented with the necessary exposure analysis using mapping, modelling and hazard analysis to assess industry and corporate risk. The evaluations should include calculating a probability profile of occurrence and impacts of hazard events in terms of their characteristics and factoring these elements into the firm's decision-making process. Thus, risk identification and analysis provide for informed decision-making on business investment that will effectively reduce the impacts of potential disaster events and prioritization of risk management efforts.

Second, risk reduction involves measures to avoid, mitigate or prepare against the destructive and disruptive consequences of hazards to minimize the potential financial impact. The mitigation measures are actions aimed at reducing the overall risk exposure associated with disasters. This requires an ex-ante business strategy that combines mitigation investments and pre-established financial protection. In this respect, firms can prevent natural disaster losses by avoiding investment in disaster prone regions (i.e. prevention investments) or they may take actions to locate and structure its business operations to avoid heavy investments in disaster prone regions. Such actions require short- and long-term strategic business planning and disaster recovery mechanisms, such as those pertaining to supply chain management. Risk mitigation planning is aimed at taking into account the economic impacts of disasters such as earthquakes. The access to relevant information is important to better-informed decision making and planning. For example, access to hazard information such as frequency, magnitude and trends are required for disaster risk mitigation for corporate investment decisions.

Finally, risk transfer mechanisms enable the distribution of the risks associated with natural hazard events such as floods and earthquakes to reduce financial and economic impacts. This might not fully eliminate the firm's financial risk exposure but it allows risk to be shared with other parties. The common risk transfer tool is catastrophic insurance, which allows firms to recover some of their disaster losses and thus managing the financial impacts of disasters. Other financial instruments include catastrophic bonds (cat-bonds) and weather risk management products. The issuance of catastrophe risk linked bonds by insurance or reinsurance companies enables them to obtain coverage for particular risk exposures in case of predefined catastrophic events (e.g. earthquakes). These catastrophe bonds allow the insurance companies transfer risk and obtain complementary coverage in the capital market and increase their capacity to take on more catastrophe risk coverage.

The use of insurance for mitigating financial losses from natural catastrophes is generally lacking in the private sector in developing countries.[7] The availability of local insurance for catastrophe risk coverage in China is low, even though local and global insurance companies are rapidly growing their life insurance business in the country. Given this situation, the insurance coverage for catastrophic risks in China's private sector is low. Comfort suggests that catastrophe risk is a public shared risk ("covariate" risk) and collective in nature, therefore, making it difficult to find individual and community solutions.[8] An effective insurance market is essential for financing post disaster recuperation and rehabilitation of firms. In the absence of a sophisticated insurance market, the government normally acts as financier for disaster recovery efforts. Governments can also influence the risk financing arrangements by encouraging the establishment of insurance pools by the local insurance industry and covering higher exposures in the global reinsurance and capital markets.

Property insurance policies for firms in earthquake prone provinces may not be readily available due to inadequate local regulation of property titles, building codes and developmental planning. In this respect, the local governments play an important role in ensuring proper public policies are implemented and regulations enforced to lower premiums and achieve higher insurance coverage in these provinces.

There is a bigger range of instruments for risk financing in the markets today. Other than insurance coverage for disaster risk, new instruments such as catastrophe risk swaps and risk-linked securities are also available in the global capital market. In 1994, the original capital market instrument linked to catastrophe risk called a catastrophe bond was introduced. Since then, more risk-linked securities are available including those providing outright funding commitments to recover economic losses from disasters. These contingent capital instruments are based on estimating the amount of risk involved through risk and loss impact estimates to build a disaster risk profile for the client. The implied risk profile is used to identify and define the risk-linked financial instruments.

Natural Disaster Risk and Firm Value

The current dynamic business environment embraces the international flow of investment to facilitate success and growth.[9] Firms with sustainable competitiveness and growth are likely to enhance their market value. Business globalisation invariably means that firms become more proactive in scouting for opportunities in foreign markets in order to sustain and build corporate value. Other than the social, economic and political risk factors normally considered in foreign investment evaluations and enterprise risk management processes, firms also need to take into account natural disaster risk. The premiums for catastrophe risk insurance are expensive and there must be a compelling case or economic incentives for firms to establish adequate insurance coverage on their assets. The gist of this chapter is to study the economic impacts of natural catastrophes from a financial management perspective.

The primary objective of the firm is to maximise shareholder wealth and an effective corporate risk management program enhances corporate value. The existent literature contains a respectable body of theories and general acceptance in the market that corporate value can be created with the proper understanding and management of risk. There is a perception of risk associated with investments and traditional finance suggests such perceptions imply that there must be a reward in the form of a risk premium for investors to take on this risk. The firm as a corporate investor is no different in that it also requires a risk premium for assuming risk. The magnitude of the firm value depends on how efficient and effective it can manage its risk exposure. From a firm value versus risk management perspective, it is possible to construe the firm's value as a function of all relevant risk factors.

While the frequency and severity of natural hazards are dictated by the natural phenomenon itself, the losses caused can be controlled by understanding and managing the business development and population density according to the vulnerability of the geographical location. Business development and population density tend to have a positive correlation and therefore natural catastrophe risk has profound social and economic impacts on the local inhabitants and economy.

Contemporary enterprise risk exposure modelling tends to ignore natural hazards and focus on estimating the severity and frequency of financial or operational exposures. The global warming phenomenon has brought about a heightened awareness of many environmental risks that may affect business. Hence, there is a need for firms and policy makers to model, monitor and measure the risk exposure from natural hazards and prepare to manage the potential impacts.

The impacts from a natural catastrophe include the loss of property, life, injury, business interruption and loss of profit. From a firm's perspective, the financial impact on its market value can be mathematically specified as:

$$\text{Firm's value at risk} = f(\text{hazard, vulnerability}) \quad (1)$$

From Eq. (1), the firm's value at risk from natural phenomena is a function of hazard and vulnerability. Equation (1) integrates the impact on the firm's value from natural phenomena and their consequence or exposure. The natural disaster risk management process has to be managed properly from the beginning therefore, it is important that firms improve the evaluation, coordination, efficiency and control of business development and management process to minimize such risks. The issues in this context are the considerations and measures that are available to firms in the natural disaster risk management process.

Coase's theory of the firm stresses that the impetus for the emergence of business corporations is the specialised institutional structure that comes into being to reduce the transaction costs.[10] Since the threat of natural disasters, like the volatility of financial prices, implies potential transaction costs to the firm, it is imperative to manage catastrophe risk as it can affect the cost of capital, the cost of production, and revenues. Financial theory suggests that rational firms would hedge their risk exposure to remove the variability in their cash flows. The significance of this view is that by removing variability, firms enhance the predictability in cash flows allowing them to invest in future projects without uncertainty about the negative impact of price fluctuations. The manifestations of variability as a result of a natural catastrophe are disruptions to the firm's supply chain, production, logistics, manpower and clientele. The management issues to be addressed in relation to catastrophe risk management using risk transfer instruments are moral hazard and adverse selection. Moral hazard occurs when the firm fails to implement preventive measures after the risk transfer has taken place and reports excessive losses. Adverse selection happens if the firms uses inside knowledge about the exposure to obtain more favorable terms in the risk transfer policy from the issuing company.

Figure 5.1 is corporate disaster risk environment. The total corporate risk is the sum of the business risk and market risk, including any disaster risk. Another aspect of corporate risk is the firm's market risk, which measures the firm's risk to a well-diversified investor. Theoretically, it is measured by the firm's beta (β) and it considers both corporate and stockholder diversification. The firm's breadth of operations, therefore its investments, will influence risk exposure depending on whether its clients tend to concentrate in economic sectors and assets that are highly exposed to disaster risk. Local small business enterprises are thus more likely to be more vulnerable to natural disasters than larger firms that are more geographically dispersed. Geographical diversification through a wide network allows firms to diversify disaster risk.

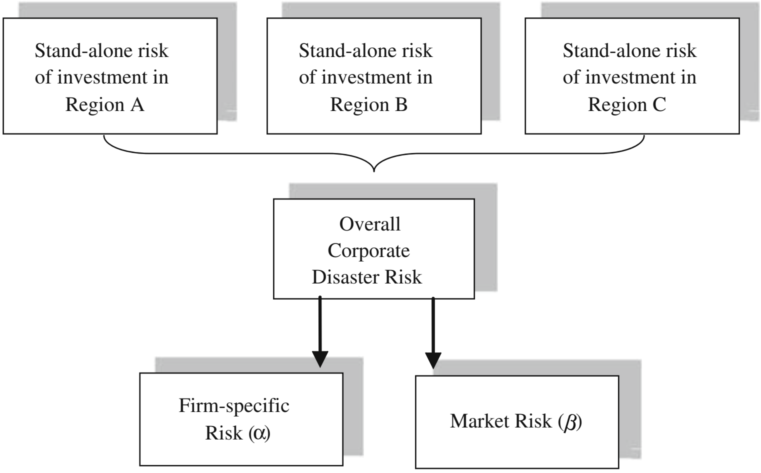

Fig. 5.1 Corporate disaster risk environment

The firm's overall exposure to natural catastrophes like earthquake need to be analyzed based on the region's vulnerability to assess the collective need for risk mitigation arrangements. Therefore, it is necessary to identify and map the major catastrophe risks that affect the region and assess how the business can be organised by adopting a risk neutral structure and/or how to obtain aggregate risk-financing arrangements.

The financial impact of natural disasters is determined by the frequency of an event occurring and by the severity of the resulting loss. The vulnerability to natural catastrophes can be reduced significantly through risk mitigation to lessen the impact of disasters. The catastrophe risk exposures in individual investment projects can be mitigated using a project-based approach to manage catastrophe risk through risk transfer such as insurance to reduce specific project exposures. Risk can also be reduced through corporate planning by building earthquake resistant structures, implementing risk neutral logistics or supply chain, market diversification and other such actions that minimise the overall asset at risk of the firm.

Financial Issues

Natural disasters can cause serious financial issues for firms as they affect the efficient management and performance of their assets and liabilities. The structural risks associated with natural disasters constitute one of the major sources of risk for most enterprises.[11] Disaster hazards can cause damages and losses to firms in partial or total destruction of assets and disruptions in service delivery. Natural disasters also cause macroeconomic effects in the economy as a whole and can bring significant changes in the macroeconomic environment. The effects of a natural disaster can interact with some of the normal risks faced by firms, including strategic management, operational, financial and market risks. These effects will reveal corporate vulnerabilities related to poor financial decisions.

The following financial issues in relation to risk management are analysed in this section:

- systematic and unsystematic risk exposure
- investment evaluation and planning
- investment to meet strategic demands
- financial risk management and compliance

Firms are constantly trying to develop more efficient models to evaluate the size and scope of risk exposure consequences using risk modelling approaches such as shareholder value at risk (SVA), value at risk (VAR) and stress testing.

Systematic and Unsystematic Risk

The overall corporate risk can be divided into *alpha* (the competency of the company's management or unsystematic risk) and *beta* (the market or systematic risk). The *alpha* risk is of an idiosyncratic nature can be eliminated by diversifying the investment portfolio, leaving *beta* as the main variable. The risk exposure of a firm can come from the political, economic or operating environments. The operating environment refers more specifically to the idiosyncratic internal and external environments in which the firm conducts it business and the inherent risks to the firm. In this context, the natural disaster risk posed by earthquakes and floods would fall within the definition of external environment. The implication of disaster risk in the internal environment would be related to the internal processes and resources available to manage this risk.

In terms of unsystematic effects of natural disasters like an earthquake, losses related to disruptions in service delivery are the result of a combination of the direct damages to the firm's assets institution and its human resource. The better prepared a firm is in risk managing its resources the lesser the impact of damages and losses to its assets and facilitate in post-disaster business recovery. Systematic risk effects to the firms can be illustrated by damages to the overall infrastructure in the region causing major disruptions to its operations even if the firm is reasonable unscathed at the micro level.

Government normally intervenes in disaster risk management to mitigate systemic risk as damage from disasters tends to be large and locally covariate and the remedial actions are targeted at the provision of public goods, such as infrastructure. The World Bank (2000) suggests that governments are more effective in covering covariant risks, while most idiosyncratic or unsystematic risks may be handled better by private providers.[12]

Investment Evaluation

An investment evaluation is conducted when a firm is considering a major expenditure. The variables taken into consideration are the cash flows, growth potential and risk associated with the project. The common tools used in investment evaluation are the net present value and internal rate of returns methods. Both these methods incorporate a parameter to measure the risk exposure inherent in the project. As the basic tenet of financial management is one of risk-return optimization. A central feature in modern risk management is the issue of risk and return relationship in investment decisions. The basic link between risk and return says that greater rewards come with greater risk and firms investing in a high natural disaster prone area would need to acknowledge this in their investment. This acknowledgement of catastrophe risk in investment evaluation is similar to accounting for political or economic risks of a country.

The price of risk is commonly referred to as the risk premium. A firm as the investor would demand a risk premium commensurate with the risk characteristics of their investment for the higher risk exposure of operating in a region with greater natural disaster risk. The risk premium to compensate for potential disaster risk can be built into the risk equation by factoring in liquidity risk from destabilizing cash fluctuations, and default or credit risk. Moreover, liquidity risk and credit risk interact under disaster conditions escalating risk premium and thus the cost of capital. This will impact on firms after the disaster when they go back into the capital markets to raise credit to rebuild their business.

Natural disasters typically trigger operational risks resulting in disruptions to cash flows and possible default of loan obligations to creditors. However, firms with efficient liquidity management will minimize the disaster effects on cash flows. The nature and magnitude of the disaster and clients' profile are factors that will influence the severity of cash flow disruptions and the ensuing credit risk. The firm can manage a credibility problem and spiralling cost of capital from a disaster if it made prior financial arrangements with creditors. These effects may lead to short term liquidity crises and heightened cost of capital in the medium term for firms. Credit risk is particularly heightened by a disaster due to disruptions to cash flows and serious loss of assets used as collaterals for loans. Unless prior arrangements are in place for creditors to mitigate repayment risks and redress the deterioration in the quality of securities, firms may face delinquency actions and loss of financial facilities.

Strategic Investment

Firms can reduce cash flow variability through business portfolio diversification by engaging in different investments, different locations and activities whose returns are not perfectly correlated. In the context of natural disaster risk management, strategic investment refers to making a financial commitment in a location after considering the risk implications and the available investment alternatives. That is, investment in risky environments must be consistent and sensitive to the risk and return profile of the firm. For instance, making a decision to invest in a new supply chain process in a disaster prone area may require looking at risk neutral alternatives. The risk neutral option may be more costly but would be appropriate if the new supply chain is to service the entire firm's operations. A Cost Effectiveness Analysis (CEA) technique can be used to compare the monetary costs of different options that provide the same physical outputs.

The commercial challenges after a natural disaster are the resumption and maintenance of client services and the financial viability of the business. Firms are caught unprepared and will struggle during a disaster to provide emergency and recovery services to their clients without adversely affecting its own financial position. The strategic perspective of disaster effects is on the adequacy of organisational and financial planning on the part of management in relation to the firm's business growth and the resultant structural design. Firms that have experienced rapid growth but do not comprehensively plan and design their business model around a disaster contingency plan are likely to be more affected by a disaster. Rapid business expansion without a appropriately well designed business model, planned investments and logistics addressing disaster risk will likely experience exacerbated problems during a disaster.

Risk Management and Compliance

To fully address corporate risk exposure with respect to natural disasters, companies need a comprehensive risk management process that identifies and mitigates the major sources of risk. Formulating a detailed risk program with capabilities for risk identification, assessment, measurement, mitigation, and transfer is necessary in a complete risk management strategy. A comprehensive corporate risk management process requires effective techniques that provide a systematic evaluation of risks, which then enables risk managers to make judgments on acceptable risks. Such a process should allow insight into primary areas of uncertainty by identification of the risk factors, highlighting likely outcomes of events and measuring the possible financial impact on the company. The process must also have built-in techniques that can provide a cost-benefit analysis of hedging options as a basis for prioritizing risk strategies. Through the risk management process, a company is able to set its risk tolerance level and any unwanted exposure may be avoided or hedged and the company is left bearing the risk it is willing to assume.

A firm-wide risk management system, using tools like the value at risk (VaR) model, which is capable of capturing the aggregate effect of financial risk exposure to financial, is important to enhance the company's overall market value. The VAR model summarizes the value at risk in a worst case scenario of possible loss under normal conditions.

Conclusions

The severe climatic changes brought about by global warming are evident by the freezing temperature which caused damages amounting to billions of dollars in

China in February 2008. The rapidly changing built environment in China also means that new risk assessment models need to be developed to accurately reflect and risk assess the real impact. Financial risk modelling and management using computer simulations incorporating probabilistic and statistical models would be valuable for evaluating potential losses from future natural catastrophes for better managing potential losses. Firms operating in high natural disaster risk areas should use risk modelling for investment evaluation, risk mitigation, disaster management and recovery planning as part of the overall enterprise wide risk management strategy. They also need to identify new business strategies for operating in disaster prone regions and financial instruments to manage risk.

Governments play an important role in financial markets in encouraging financial institutions to support borrowers in risk reduction and to mitigate the impacts of natural disasters. Government policies to prevent the practice of prevention investments is needed to break the disasters reconstruction-disasters-new reconstruction cycle as alluded by the Chinese government in Wenchuan. The local Chinese insurance sector is still relatively underdeveloped in relation to risk estimation, underwriting standards, and management capabilities. The inadequate construction and building standards combined with weak enforcement of building codes in many regions in China increases earthquake exposure. In the short term, the gradual development of the local insurance markets is a more practical approach to extend catastrophe insurance coverage in China. The establishment of a sophisticated risk transfer capital markets should be a longer-term objective. The development of the insurance markets must go hand in hand with the better development planning, and building regulatory and enforcement mechanisms.

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Chapter 6
Disaster Risk Management in China

Disasters have been endemic throughout history. In Judeo history, the flood survived by Noah was about as complete a disaster to contemporary humankind as can be imagined. Egypt was plagued with droughts and floods of the Nile. In Greek/Roman culture, events such as eruptions of Mount Vesuvius caused tremendous suffering and damage. Similar disasters disrupted human activity throughout the world, to include unrecorded events at Easter Island. The International Federation of Red Cross and Red Crescent Societies stated that over a recent 10 year period, almost two billion people have been affected by disasters.[1] People in Asia accounted for almost 89% of the population affected by natural disasters between 1975 and 2003.[2]

In very recent activity, we have continued to see disasters, such as the 2004 tsunami in the Indian Ocean,[3] European flooding in August 2005, hurricane Katrina in the US in September 2005,[4] and Sichuan earthquakes in 2008. These disasters were all geological. There have been biological disasters such as the SARS scare, and the current swine flu virus scare. Nuclear systems receive a great deal of attention, to include the Netherlands,[5] the US,[6] Russia,[7] and elsewhere. Like all governments, the US government expends considerable effort in developing emergency response capability.[8] The US Department of Homeland Security also has systems, to include their Critical Infrastructure Protection Decision Support System (CIPDSS).[9] A common theme is that we are never prepared adequately, yet society copes, and no matter how successful response is, critics abound.[10]

We will begin the chapter with a review of the 2008 Sichuan earthquake in China and the responses to that disaster. We will then review the rich and growing field of emergency management, focusing on the use of modeling and technology to support better response. These tools include database systems, data mining, other forms of quantitative modeling, culminating in emergency management support systems. There are many software products developed to support disaster planning. In a broad sense, they cover data manipulation as well as modeling specific scenarios. Many software providers are moving to virtual services, making their products available on-line. We review a few of the applications involving database systems and data mining, followed by a review and demonstration of emergency management support systems, and one of the financial instruments designed to deal with that aspect of disaster management.

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Chinese Earthquake Disaster Management

China experienced damaging earthquakes in 2008 in Sichuan. Earthquake prediction is very difficult to predict, in terms of timing, magnitude, and location. Table 6.1 gives a listing of major Chinese earthquakes, extracted from Web sites.

Table 6.1 Major Chinese earthquakes

Time	Place	Deaths	Intensity	Comments
1036	Shanxi	23,000	?	
1057	Chihli (Hopeh)	25,000	?	
27 Sep 1290	Chihli (Hopeh)	100,000	6.7	
23 Jan 1556	Shaanxi	830,000	≈8	
13 Jul 1605	Qiongshan Hainan	3,000	X	
1731	Beijing	100,000	?	
16 Dec 1920	Ningxia-Gansu	240,000	8.6	Felt in 17 provinces; 4 cities destroyed; 10 more towns damaged
22 May 1927	Gulang Gansu	40,000	7.9	Gulang vanished; poisonous material produced
25 Dec 1932	Changma Gansu	70,000	7.6	Many aftershocks for half a year
1976	Tangshan	242,000	7.8	164,000 injured, more than 410,000 localities suffer cave breakdowns, landslide and mud-rock flows with an annual death toll of nearly 1,000; 2.62 million km^2 of land desertified; 2,460 km^2 of land becomes sand annually and more than 1.8 million km^2 of land lost due to water erosion
2 Jun 2007	Yunnan	2	6.2	Over 200 more injured, damage to houses and roads, communication
12 May 2008	Sichuan Province	87,000+	8.0	Felt in Beijing and Shanghai; over 26,000 aftershocks, billions in damage; lots of quake lakes; direct economic loss 845.1 billion RMB

Figure 6.1 shows the intensity of the series of shock over the period 12 May to 11 June 2008 in Sichuan.

China is of course not alone in facing the risks of earthquakes. Australia recorded insured losses of over $1 billion at Newcastle in 1989. For a detailed list of large earthquakes all over the world, please see http://en.wikipedia.org/wiki/List_of_earthquakes. Table 6.2 demonstrates that earthquakes can involve massive loss of life (see the 1,556 earthquake on the list). Earthquakes strike all around the world. In August, 2007 Peru was struck by a 7.9 magnitude earthquake shaking the cities of Ica, Pisco, and Chinca, resulting in 500 deaths and destruction of houses,

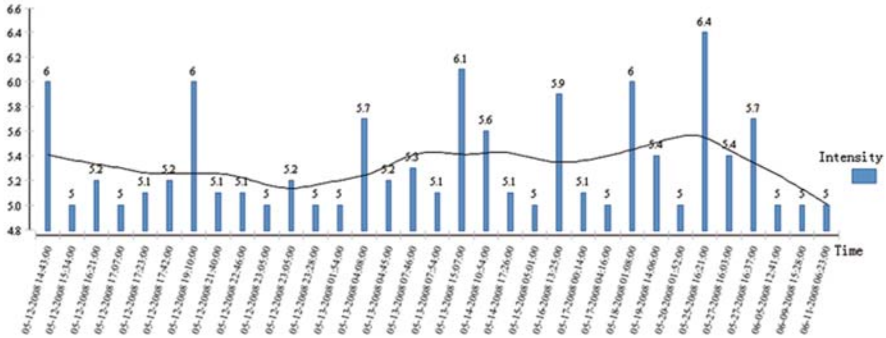

Fig. 6.1 Distribution of Sichuan earthquake aftershocks

churches, transportation and utilities.[11] In May 1970, over 50,000 died in Peru from another 7.9 magnitude earthquake. Earthquakes in Japan threaten a widespread nuclear energy system. An earthquake in 2007 caused a fire at the Kashiwazaki-Kariwa Nuclear Power Plant, leading to leaking of radioactive water into the ocean. As nuclear energy becomes more attractive, environmental groups are concerned about earthquake risk in other areas of Asia, to include Indonesia, Vietnam, and Thailand.[12]

Earthquakes also have had significant political impact (e.g., the Managua Nicaragua earthquake in 1972 has been credited with leading to the Sandinista revolution because of inadequate governmental relief response).

Earthquake Response

Earthquake response refers to actions taken to immediately save victim lives and reduce possible damage and disruption in a very short period of time. Possible measures consist of threat detection, warning message dissemination, threatened population evacuation, trapped victim search and rescue, medical care and food and shelter provision. Many nations have developed measures to cope with earthquakes.

In *Europe*, risk from natural disaster-triggered events is referred to as Natech.[13] One of the most recent earthquakes of significance was in Turkey in August 1999 at Kocaeli. This earthquake released over 20 hazardous material events, and caused the collapse of a concrete stack at an oil refinery, triggering multiple fires which burned for 4 days, leading to evacuation of thousands. Sampling identified over 100 industrial facilities that handled hazardous chemicals. The European Community is acting through regulations aimed at prevention and limiting consequences. Industrial facilities that store, use or handle dangerous substances are required to have major-accident prevention policies, with emergency plans for dealing with accidental chemical release. Facilities must carry out a hazard assessment, to include a process safety analysis, evaluate mitigation measure including protection of human health and the environment.

Table 6.2 Red Cross and Red Crescent Society objectives and progress (IRCRCS 2008)[19]

Category	Objectives	Activities	Progress
Food and basic items	0–3 months: ensure up to 100,000 families receive food, water, sanitation 1–12 months: ensure up to 100,000 families receive food enabling move to transitional shelter	Transportation Water and sanitation units set up Water purification tablet distribution Base camp and satellite stations set up	150,000 tents >120,000 quilts 250,000 clothing items 1.7 million mosquito nets 6,480 t of food
Shelter	0–3 months: ensure 100,000 families receive shelter 1–12 months: provide technical support for 1,000 health centers, 1,500 schools 3–36 months: provide earthquake-resistant houses for 2,000 rural families	Deployment of Deyang base camp Pilot projects Rural area site selection Shelter kit materials to 2,000 families	53 planes chartered to deliver tents 102,210 international tents received through end of July
Health	0–3 months: deploy medical, first aid, psychological support teams 1–12 months: Provide technical assistance and training to health clinics 3–36 months: technical assistance and training for preparedness and service	Provided technical advice and monitoring Provided technical advice and training in emergency health care, psychological first aid, psychological assessment	Rapid deployment of eight health professional teams on 2-week rotations by the end of May
Water and sanitation	0–3 months: provide drinking water, sanitation, hygiene promotion 1–12 months: provide technical assistance and training for emergency response units 3–36 months: provide technical assistance and training for emergencies, with facilities	On-the-job training and technical support	Distributed water purification tablets Deployed two M15 water and sanitation units Deployed one mass sanitation unit
Rural livelihood	0–3 months: provide technical advice and training for livelihood substitution; cash and voucher transfer 1–12 months: provide livelihoods to 2,000 families	Detailed assessment of rural livelihoods Pilot projects Grants and materials to 2,000 families and host communities	Awaiting area stabilization

In *Bulgaria*, specific measures include building codes requiring earthquake resistant design. Bulgarian hazardous material measures include a hazard assessment, to include scenarios of domino effects and impacts on communities.

In *France*, natural disaster risk prevention includes hazard identification, risk assessment, monitoring and warning programs, prevention and mitigation policies, and regulations establishing zoning, disaster preparedness and emergency response.

Germany has an integrated system of prevention and warning systems. Each disaster triggers evaluation that is used to update regulations. Emergency response plans are required with hazard risk maps published.

In *Italy*, the Department of Civil Protection held a nationwide study to evaluate civil protection plans. Scenarios of direct and indirect effects on human health, the food chain, and pollution are used for planning.

Portugal deals with earthquake risk under their Regulation for Security for Structures. An in-depth study to assess seismic vulnerability was conducted in 1997, leading to an emergency contingency plan. Portugal developed a GIS-based simulator of seismic scenarios with information on geophysical, geological, housing, structural, and population data by region.

Sweden applies an all-hazards approach to risk management and emergency response. Municipalities are required to identify local risks and generate preventive measures and emergency response plans. National agencies provide supervision, tools, guidance and support.

Australia also experiences some earthquake activity, averaging losses of $Australian 144 million per year.[14] In December 1989, Newcastle was hit by a 5.6 magnitude earthquake leading to damage to over 63,000 household insurance claims. Australia has done significant work in assessing the risk to residential buildings since that time. This may lead to the avoidance of some future damage through better building codes and land-use planning.

In the *United States*, emergency management has a long and complex history, directed by various governmental agencies, to include the Federal Emergency Management Agency. Federal, State, and Municipality governments all have regulations and building codes. Comerio[15] reviewed policy incentives designed to steer builders to construct more disaster-resistant structures. Some policies are aimed at reducing risk through growth restrictions or land-use regulations. Other policies promote safe development through mitigation of event consequences through preparedness information, building codes, and insurance. The chief of the Office of Applied Economics of the US National Institute of Standards and Technology has proposed a three step protocol to prepare for natural disaster in the context of building construction.[16] The first step is to assess risk. Tools available to evaluate risk include standards and software products. The second step is to identify alternative risk mitigation strategies, to include engineering alternatives, management practices, and financial mechanisms. The third step is to evaluate life-cycle economic effectives of alternatives. Some organizations provide standards and software to aid in this third step.

The State of *California* has a heavy history of earthquake experience. The 1994 Northridge earthquake resulted in over $12 billion in insured losses, severely damaging the insurance industry. Part of the California approach to dealing with earthquakes includes legal requirements for insurers to sell residential earthquake coverage, enacted in 1988.[17] Special insurance pools were created to assure that coverage was provided while enabling insurers to survive.

Chinese Earthquake Response

Chinese response to the 2008 Sichuan earthquakes was reported by the International Federation of Red Cross and Red Crescent Societies[18] provided a 3-month consolidated report as of 22 August 2008, outlining challenges and progress in response to the Sichuan earthquake. By August 12th, the Sichuan provincial government was credited by placing all displaced people in transitional housing. The magnitude of the disaster was demonstrated in the massive scope, with 4.5 million people losing homes. Of these, 978,000 were in urban households, who were placed in transitional housing, with 3,400 resettlement areas being build. In rural areas, 3.5 million received government subsidies to rebuild their own housing. Of these, 20,000 permanent homes had been completed by the time of the report, with another 175,000 homes under construction. Table 6.2 gives objectives and progress by relief category for the Chinese Red Cross and Red Crescent Society.

Database Support

Disaster management involves a superabundance of data. This data usually comes from a variety of sources, to include humans as well as government and private databases. Furthermore, there are usually a number of government agencies involved, each liable to have their own data to include. The problem is that in the planning stage, it is difficult to predict which specific data are going to be needed for a specific event. Fortunately, database systems exist to help deal with large quantities of data.

A database system is the first step in a systematic approach to disaster management. There are many database products. Database systems can store information provided by organizational reports, such as government data related to types of disasters, and add external data from sources such as industry or local government entities. Users can also find pertinent data from the web. Relational database systems are most often used by individuals or small organizations. They provide effective means to organize and store data with efficient retrieval capabilities. Lowe discusses semantic architectures for database systems to organization geospatial data into knowledge management systems.[20] A step up in the hierarchy of database products is online analytical processing (OLAP), providing access to report generators and graphical support. Data marts are more powerful database products, followed in size by data warehouses, large scale systems appropriate for very large organizations.

Disaster information management systems (DIMS) have been developed to store such data.[21] A minimum set of requirements for a DIMS are:

1. The ability to recognize and handle different disaster data sources, to include geographical information, registry information, and aid information.
2. The ability to handle disparate disaster data formats. Data can be obtained from diverse data sources to include e-mails, documents, pictures, movies, and audio files.

Some data can be gathered prior to disaster. Geographical data includes information on population, infrastructure, and natural ecosystems. Hazard information is data on the disaster event itself, to include location, severity, and probabilities. Locators are needed to track the current location of victims. Registries are needed to identify victim families, those requiring medical attention, and critical contact information concerning human resources for dealing with various aspects of a disaster. Data can come in many formats. More advanced data types include 3D and virtual reality content. Standardization reduces the difficulties of sharing information.

To prevent accidental or intentional loss of data, and to ensure efficient retrieval and distribution, a centralized data repository (such as a data warehouse) is desirable at a secure location. This will enable more efficient querying of data and thus expedite subsequent analysis. Security calls for a back-up site at a different physical location. Data at both the primary and back-up sites should be periodically monitored for accuracy and operational readiness. Some of the data stored in these systems may be sensitive, to include critical national infrastructure content concerning transportation, power, and communication networks, as well as military facilities. Individual information can also be sensitive, such as personal identification data that might lead to compromise by identity thieves (social security numbers, etc.), or sensitive medical information on individuals. Access management and encryption systems exist to safeguard such data, but these systems need to be properly implemented.

Some geographical data needs to be constantly updated for location. Critical assets may be moving quite often in a disaster situation. Part of the dynamic of life is the constant development of new technologies.

Example Database Support

Database support was critical in health management after Hurricane Katrina.[22] Of the metropolitan New Orleans population of about 1.3 million, there were over 39,000 veterans with an average of 1,717 patients per day receiving care. Veterans Affairs medical facilities are extensively computerized. During the emergency, about 80% of all residents were evacuated. Tens of thousands of New Orleans evacuees required medical support of an urgent type. The Department of Veterans Affairs conducted a study of data accessed in their system. Veterans Affairs patients had a much better rate of receiving appropriate and uninterrupted care. Approximately 1,000 patients per day had data accessed in the month after the hurricane, with data transmitted to over 200 sites in 48 states by at least 2,300 users. This example supports the value of emergency management support systems.

Access to data is an important requirement for almost every organization. Business intelligence in this context is supported by storing data (data warehouse and related systems) and conducting studies using this data to solve business problems (one means to do this is through data mining). Vast quantities of data often provide opportunities to data mine. While data warehouses are not requirements to do data mining, data warehouses store massive amounts of data that can be used for data mining. Data-mining analyses are also often accomplished using smaller sets of data organized in online analytic processing systems or in data marts.

Data Mining Support

Data mining involves the use of analysis to detect patterns and allow predictions. It is not a perfect science – the intent of data mining is to gain small advantages, because perfect predictions are impossible. This can be valuable in the support of disaster management. Applications include management of electricity transmission networks[23] or identification of terrorist activity.[24]

In order to systematically conduct data mining analysis, a general process is usually followed. There are some standard processes, two of which are described in this chapter. One (CRISP) is an industry standard process consisting of a sequence of steps that are usually involved in a data mining study. The other (SEMMA) is specific to SAS. While each step of either approach isn't needed in every analysis, this process provides a good coverage of the steps needed, starting with data exploration, data collection, data processing, analysis, inferences drawn, and implementation.

Data Mining Process

There is a Cross-Industry Standard Process for Data Mining (CRISP-DM) widely used by industry members. This model consists of six phases intended as a cyclical process (see Fig. 6.2).

- *Business understanding*: Business understanding includes determining business objectives, assessing the current situation, establishing data mining goals, and developing a project plan.
- *Data understanding*: Once business objectives and the project plan are established, data understanding considers data requirements. This step can include initial data collection, data description, data exploration, and the verification of data quality. Data exploration such as viewing summary statistics (which includes the visual display of categorical variables) can occur at the end of this phase. Models such as cluster analysis can also be applied during this phase, with the intent of identifying patterns in the data.

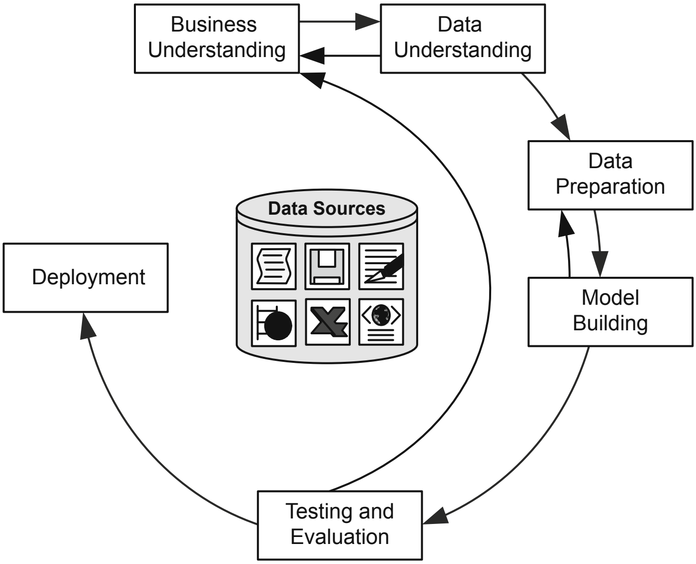

Fig. 6.2 CRISP-DM process

- *Data preparation*: Once the data resources available are identified, they need to be selected, cleaned, built into the form desired, and formatted. Data cleaning and data transformation in preparation of data modeling needs to occur in this phase. Data exploration at a greater depth can be applied during this phase, and additional models utilized, again providing the opportunity to see patterns based on business understanding.
- *Modeling*: Data mining software tools such as visualization (plotting data and establishing relationships) and cluster analysis (to identify which variables go well together) are useful for initial analysis. Tools such as generalized rule induction can develop initial association rules. Once greater data understanding is gained (often through pattern recognition triggered by viewing model output), more detailed models appropriate to the data type can be applied. The division of data into training and test sets is also needed for modeling.
- *Evaluation*: Model results should be evaluated in the context of the business objectives established in the first phase (business understanding). This will lead to the identification of other needs (often through pattern recognition), frequently reverting to prior phases of CRISP-DM. Gaining business understanding is an iterative procedure in data mining, where the results of various visualization, statistical, and artificial intelligence tools show the user new relationships that provide a deeper understanding of organizational operations.
- *Deployment*: Data mining can be used to both verify previously held hypotheses, or for knowledge discovery (identification of unexpected and useful relationships). Through the knowledge discovered in the earlier phases of the CRISP-DM

process, sound models can be obtained that may then be applied to business operations for many purposes, including prediction or identification of key situations. These models need to be monitored for changes in operating conditions, because what might be true today may not be true a year from now. If significant changes do occur, the model should be redone. It's also wise to record the results of data mining projects so documented evidence is available for future studies.

This six-phase process is not a rigid, by-the-numbers procedure. There's usually a great deal of backtracking. Additionally, experienced analysts may not need to apply each phase for every study. But CRISP-DM provides a useful framework for data mining. In addition to the CRISP-DM there is yet another well-known methodology developed by the SAS Institute, called SEMMA. The acronym SEMMA stands for *s*ample, *e*xplore, *m*odify, *m*odel, *a*ssess. Beginning with a statistically representative sample of your data, SEMMA intends to make it easy to apply exploratory statistical and visualization techniques, select and transform the most significant predictive variables, model the variables to predict outcomes, and finally confirm a model's accuracy.

Specific to emergency management, Wickramasinghe and Bali[25] provided a process for data mining:

- Develop understanding of the decision problem, relevant prior knowledge, decision maker goals
- Create a target data set for analysis
- Clean and preprocess the data (fill in missing fields, clean out noise, etc.)
- Focus on relevant variables for the specific application
- Identify the specific data-mining task (clustering, classification, regression, etc.)
- Select appropriate algorithms/models
- Search for patterns of interest (the actual data mining activity)
- Interpret patterns, and if necessary, return to prior steps
- Consolidate knowledge discovered, prepare reports.

Data mining can fit into a broader activity called knowledge management. Knowledge management uses technology to support the acquisition, generation, and transfer of knowledge in a specific organizational process. Usually both data and tacit human expertise is tapped, leading to the use of knowledge support systems.

Quantitative Model Support

Operations research is the application of mathematical modeling to aid decision making. It is really a process, based upon gathering sound and scientific data, and implementing this data in mathematical models of the key decision elements, leading to sounder decision making. A recent study analyzed five major emergencies and the response applied, with the intent of identifying the value of operations research models.[26] That study identified nine ways in which these models can aid in emergency planning and response:

1. Prepositioning supplies and equipment (location of resources)
2. Inference algorithms (pattern identification)
3. Evacuation decision-making (probability assessment)
4. Triage (queuing analysis of medical facilities)
5. Second- and third-tier responders (dispatch reinforcing response resources)
6. Volunteer and off-duty personnel management
7. Logistics near-the-scene (distribution of emergency supplies)
8. Handling 911 calls (resource response prioritization)
9. Reducing telephone and radio congestion (queuing analysis of communications resources)

This list focuses on emergency response functions. In parentheses, we have added general operations research problem types. A variety of tools are applied, to include statistics and probability, queuing (waiting line) analysis, and optimization models (some of which are discussed in the emergency management support system section to follow).

Example Emergency Management Support Systems

A number of software products have been marketed to support emergency management. These are often various forms of a decision support system. The Department of Homeland Security in the US developed a National Incident Management System. A similar system used in Europe is the Global Emergency Management Information Network Initiative.[27] While many systems are available, there are many challenges due to unreliable inputs at one end of the spectrum, and overwhelmingly massive data content at the other extreme.

Decision support systems (DSS) have consisted of access to tailored data and customized models with real-time access for decision makers. With time, as computer technology has advanced and as the Internet has become available, there is a great deal of change in what can be accomplished. Database systems have seen tremendous advances since the original concept of DSS. Now weather data from satellites can be stored in data warehouses, as can masses of point-of-sale scanned information for retail organizations, and output from enterprise information systems for internal operations. Many kinds of analytic models can be applied, ranging from spreadsheet models through simulations and optimization models. DSSs can be very useful in support of emergency management. They can take the form of customized systems accessing specified data from internal and external sources as well as a variety of models suitable for specific applications needed in emergency management situations. The focus is on supporting humans making decisions. If problems can be so structured that computers can operate on their own, decision support systems evolve into expert systems. Expert systems can and have also been used to support emergency management.

Systems in place for emergency management include the US National Disaster Medical System (NDMS), providing virtual centers designed as a focal point for information processing, response planning, and inter-agency coordination. Systems have been developed for forecasting earthquake impact.[28] This demonstrates the need for DSS support not only during emergencies, but also in the planning stage.

Information technology can be of best use in gathering and organizing data. But systems also need to be easy to use during crises. The tradeoff is that the more comprehensive the data that is contained, the more difficult they are to use. Systems supporting earthquake response need to address the following:

- Damage assessment of structures after earthquakes
- Lessons of post-earthquake recovery
- Rehabilitation and reconstruction
- Public policy
- Land use options
- Urban planning and design

Among the model system support includes computer agents, to aid in using computer automatic analysis over distributed systems, highly useful in fast-moving complex situations.[29] Simulation provides a means to deal with probabilistic factors, and has been applied in flood monitoring and predicting in China.[30] A statistically oriented system e-EcoRisk UE (A regional enterprise network decision-support system for environmental risk and disaster management of large-scale industrial spills) was developed to help manage dam breakage risk in Spain.[31] They cannot be expected to deal with all contingencies, as the nature of an emergency includes unexpected elements. However, prior planning provides improved odds of adequate coping with emergencies.

A major recourse in emergency response is the transportation network.[32] An example of an emergency management support system (EMSS) focusing on a specific type of problem is a system based on a network flow optimization model of road systems in Taiwan.[33] Another example is an optimization model for ambulance location.[34] Many systems have been developed to support nuclear emergencies,[35] to include the RODOS (real-time on-line decision support system).[36] In the field of biological threats, RealOpt has been developed as a simulation-based decision support system for emergency dispensing clinics to plan large-scale dispensing of care.[37] RealOpt was applied to DeKalb County, IL in an anthrax-drill exercise, while seven other counties in the same area dealt with the drill without its support. DeKalb County had the highest throughput of subjects processed (50% more than the second-place county), and was evaluated as having the most efficient plan, the most cost-effective in terms of labor, and the most efficient in terms of average waiting time, queue length, and utilization rates.

RODOS System for Nuclear Remediation

Nuclear emergencies are a prime example of disaster management. Hopefully, such events are extremely rare, although we have seen such events in both the United States and in the Soviet Union. Zähringer and Wirth[38] noted that decision making planning is critical, while clear and unambiguous models are needed for fast response, in such events input data are highly uncertain and disputable. Initially, the focus is on providing uncontaminated food and medical supplies. Later, decisions call for broader data sets, allowing analysis balancing cost, environmental impact, and not only medical by adverse psychological effects.

RODOS[39] is an acronym for real-time online decision support system developed in Europe to deal with nuclear accidents such as Chernobyl. RODOS consists of three subsystems:

1. An analyzing subsystem (ASY) which processes incoming data to forecast location and amount of contamination expected by time;
2. A countermeasure subsystem (CSY) which simulates potential countermeasures to check for feasibility and to calculate expected benefits on a number of attributes;
3. A multiple criteria selection subsystem (ESY) to rank countermeasure strategies based on measures provided by CSY as well as decision maker preferences.[40]

A hypothetical radiological accident scenario was used in one workshop, assuming a nuclear power plant accident with the nuclear reactor immediately shut down. A few hours later, radioactive material was assumed released into the atmosphere, with the subsequent cloud blown over a large food production area. The ASY subsystem provided a map with radiation densities. It was assumed that all necessary countermeasures were taken, to include distribution of iodine to individuals, sheltering, or evacuation. Green houses and animal stables were closed and agricultural production areas covered along with animal and human food supplies. Figure 6.3 provides the criteria hierarchy.

The alternatives used in exercises are given in Table 6.3, along with estimated values for criteria. The RODOS system generated values for ten of these criteria (doses, man-hours, numbers of workers, food impact, area affected), while experts and stakeholders assessed values for five criteria (Supplies, Costs, and Acceptance rates) on a 0–100 scale.

Preference elicitation of workshop participants was accomplished through the ESY subsystem. This yielded a set of weights for each of the 15 criteria listed in Table 6.1. The system then provided graphical display of relative performance of each of the nine alternatives over the four major criteria categories of radiation effectiveness, resource usage, impact, and acceptance. The system also provided graphical sensitivity analysis. RODOS provided descriptive reports to include maps of predicted, possible, and subsequently experienced dose distributions with evaluations of benefits and deficiencies of the countermeasure strategies analyzed. The

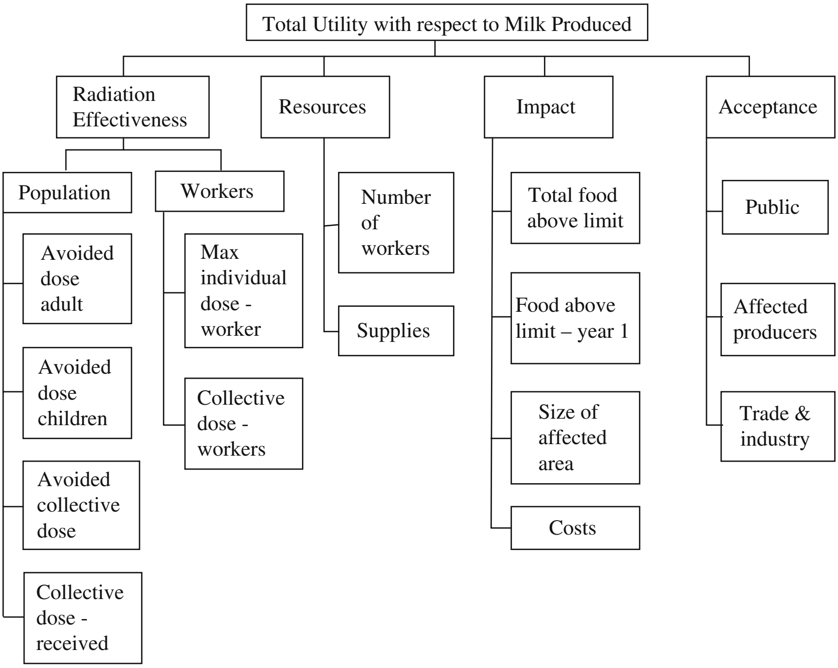

Fig. 6.3 RODOS hierarchy

Explanation Module provided comparative reports evaluating two strategies. A sensitivity analysis report provides graphs illustrating the effect of changing preference weights.

The RODOS system gives an example of an emergency decision support system providing support to an accident domain where probability of occurrence is low but consequences are severe. Similar systems can also be developed around any disaster scenario, including repetitive events such as hurricane planning.

Chinese Catastrophe Bond Modeling

The 2008 Sichuan earthquake caused loss to the Chinese insurance sector in excess of 65 million RMB about 70 days after the quake. Figure 6.4 gives the claim payoffs of the insurance industry from the Wenchuan Earthquake disasters.

Motivated by various catastrophe (*CAT*) events such as the above earthquake and Swine Flu, the (re)insurance company created lots of CAT risk instruments in order to hedge high CAT risk exposures, which include substantial financial losses from natural disasters such as earthquakes.

The first CAT instrument, i.e., CAT equity put option, was issued to offer the CAT option owner the right to issue convertible preferred shares at a fixed price

Table 6.3 Alternatives and criteria performances in RODOS

Criteria	No action	Milk disposal	Milk process	Storage	Cow removal *T* 0	Cow removal $T > 0$	Clean cows, feed	Add food concentrates
Avoided adult dose	0	0.677	0.0144	0.0000316	0.012	0.0045	0.00169	0.041
Avoided children dose	0	1.35	0.0288	0.0000632	0.239	0.009	0.0033	0.081
Avoided collective dose	0	12,000	1,756.62	71.0215	6,194.81	1,580	1,140	2,560
Collective dose	12,600	789	10,900	12,600	6,480	11,100	11,500	10,100
Max worker dose	0	0	0	0	0.00125	0.000901	0.00107	0
Collective worker dose	0	0	0	0	2.42	0.614	0.788	0
Number workers	0	0	0	0	658	532	547	0
Total food above	112 million	112 million	16.1 million	112 million	48.6 million	83 million	108 million	14.6 million
Food above year 1	122,000	122,000	0	1,600	3,120	3,120	3,120	0
Area km^2	2,640	2,640	1,787	2,640	179	2,640	2,615	1,787
Supplies	0	10	10	20	40	40	30	80
Costs	90	100	20	50	20	20	20	35
Public	0	100	5	15	80	80	30	5
Affected producers	0	20	70	60	100	100	80	50
Trade and industry	0	40	5	50	80	80	60	5

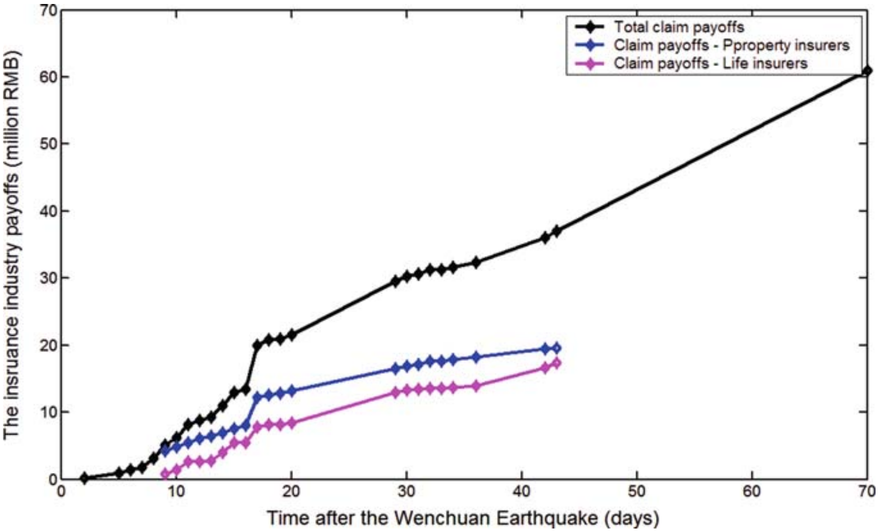

Fig. 6.4 Insurance payoffs of for the Wenchuan earthquake[41]

by RLI Corp. in 1996. Since then, the contingent capital market is growing very rapidly due to the increase of unanticipated catastrophic events. Therefore, there is a great demand for insurance and reinsurance companies to appropriately price these contingent capital and instruments such as CAT bonds.

The notion of securitizing catastrophe risks became prominent in the aftermath of Hurricane Andrew.[42] Giant insurance companies such as AIG, Hannover Re, St. Paul Re, and USAA completed the first experimental transactions in the mid-1990s. An immediate huge market then followed: $1–2 billion of issuance per year for the 1998–2001 period, and over $2 billion per year following 9-11 and approximately $4 billion on an annual basis in 2006 following Hurricane Katrina. This market continued to grow rapidly through 2007 because a number of insurers sought diversification of coverage through the market.[43] Table 6.4 gives market amount of the earthquake bonds in North America and Japan from 1997 to 2007.

Catastrophe bonds are the most common type of CAT risk-linked securities and have complicated structures. Catastrophe bonds, or CAT bonds, refer to a financial instrument devised to transfer insurance risk from insurance and reinsurance companies to the capital market. The payoff of CAT bonds dependent on qualifying trigger event(s):Natural disasters, e.g., earthquakes, floods, hurricanes or man-made disasters, e.g., fire, explosions, terrorism. We will review modeling approaches of CAT bonds as follows.

Traditional derivative pricing approaches using Gaussian assumptions are not appropriate when applied to these instruments such as CAT bond due to the properties of the underlying contingent stochastic processes. There are evidences that catastrophic natural events have (partial) power-law distributions associated with

Table 6.4 Market amount of earthquake bonds from 1997 to 2007

Year	North America	Japan
1997	112	90
1998	145	–
1999	327.8	217
2000	486.5	217
2001	696.9	150
2002	799.5	383.6
2003	803.8	691.2
2004	803.3	310.8
2005	1,269	138
2006	2,228.7	824.1
2007	3,630	1,160
Total	11,302.5	4,181.7

their loss statistics.[44] This overturns the traditional log-normal assumption of derivative pricing models. There are also well-known statistical difficulties associated with the moments of power-law distributions, thus rendering it impossible to employ traditional pooling methods and consequently the central limit theorem. Several studies have been done to pricing models with respect to catastrophe derivatives such as CAT bonds. Geman and Yor[45] analyzed catastrophe options with payoff $(L(T) - K)+$ where $L(T)$ is the aggregate claim process modeled by a jump–diffusion process. Cox and Pedersen[46] priced a CAT bond under a term structure model together with an estimation of the probability of catastrophic events. Dassios and Jang[47] used a doubly-stochastic Poisson process for the claim process to price catastrophe reinsurance contract and derivatives. Jaimungal and Wang[48] studied the pricing and hedging of catastrophe put options (CatEPut) under stochastic interest rates with a compound Poisson process. In contrast, Lee and Yu[49] adopted a structural approach to value the reinsurance contract, where they use the idea of credit risk modeling in corporate finance. They allow the reinsurer to transfer the risk to the capital market via CAT bonds and, in effect, to reduce the risk of the reinsurer's default risk. Since the payments from CAT bonds cannot be replicated by the ordinary types of securities available in financial markets, the pricing has to be done in the incomplete market model.

The most important feature of Cat bonds is the conditional payment. Trigger conditions are generally divided into three categories: indemnity-based trigger conditions, index-based trigger conditions and parametric trigger conditions. An indemnity trigger involves the actual losses of the bond-issuing insurer. It is very popular in the early times of Catastrophe bond market. An industry index trigger includes an industry index, e.g., an index created from property claim service (PCS) loss estimates. A parametric trigger is based on quantitative parameters of the catastrophe event, for example, earthquake magnitude, central pressure wind pressure, wind speed, rainfall of hurricane and so on.

Conclusions

Disaster management is a very important topic. While humans have developed the ability to cope with more of nature's challenges, humans also build ever more complex systems that involve greater risks. This chapter has presented the 2008 Sichuan earthquake as an example of the magnitude of the challenge. It then presented some programs and tools that have been developed to deal with disasters. These include database systems, data mining, and emergency management systems. An example EMSS (RODOS) supporting nuclear accident incidents was demonstrated. Finally, CAT bonds were described as a means to cope with the financial aspects of emergency incidents.

Emergency management will always be with us. By their nature, emergencies catch us unprepared. However, as described in this chapter, government agencies around the world have developed programs and systems to help cope. The ability to share resources in terms of food and medical supplies over common transportation networks helps alleviate disasters a great deal.

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Chapter 7
Value-Focused Supply Chain Risk Analysis

A fundamental premise of Keeney's book (1992)[1] is that decision makers should not settle for those alternatives that are thrust upon them. The conventional solution process is to generate alternative solutions to a problem, and then focus on objectives. This framework tends to suppose an environment where decision makers are powerless to do anything but choose among given alternatives. It is suggested that a more fruitful approach would be for decision makers to take more control over this process, and use objectives to create alternatives, based on what the decision makers would like to achieve, and why objectives are important.

Hierarchy Structuring

Structuring translates an initially ill-defined problem into a set of well-defined elements, relations, and operations. This chapter is based on concepts presented in Keeney, and in Olson.[2]

Before we discuss hierarchies and their structure, we should give some basic definitions. Keeney and Raiffa[3] gave the following definitions:

> *Objective* – the preferred direction of movement on some measure of value
> *Attribute* – a dimension of measurement

Keeney and Raiffa distinguish between *utility* models, based upon tradeoffs of return and risk found in von Neumann-Morgenstern utility theory and the more general *value* models allowing tradeoffs among any set of objectives and subobjectives. *Preferential independence* concerns whether the decision maker's preference among attainment levels on two criteria do not depend on changes in other attribute levels. *Attribute independence* is a statistical concept measured by correlation. Preferential independence is a property of the desires of the decision maker, not the alternatives available.

The simplest hierarchy would involve VALUE as an objective with available alternatives branching from this VALUE node. Hierarchies generally involve additional layers of objectives when the number of branches from any one node

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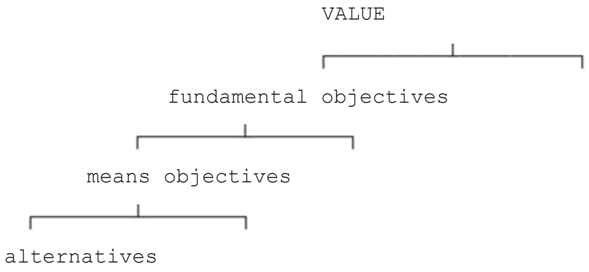
exceeds some certain value. Cognitive psychology has found that people are poor at assimilating large quantities of information about problems. Saaty used this concept as a principle in analytic hierarchy development, calling for a maximum of from seven branches in any one node in the analytic hierarchy process (AHP).[4]

Desirable characteristics of hierarchies given by Chap. 2 of Keeney and Raiffa (1976) include:

Completeness – objectives should span all issues of concern to the decision maker, and attributes should indicate the degree to which each objective is met.
Operability – available alternatives should be characterized in an effective way.
Decomposability – preferential and certainty independence assumptions should be met
Lack of Redundancy – there should not be overlapping measures
Size – the hierarchy should include the minimum number of elements necessary.

Keeney and Saaty both suggest starting with identification of the overall fundamental objective. In the past, business leaders would focus on profit. Keeney stated that the overall objective can be the combination of more specific fundamental objectives, such as minimizing costs, minimizing detrimental health impacts, and minimizing negative environmental impacts. For each *fundamental objective*, Keeney suggested the question, "Is it important?"

Subordinate to fundamental objectives are *means objectives* – ways to accomplish the fundamental objectives. Means objectives should be mutually exclusive and collectively exhaustive with respect to fundamental objectives. When asked "Why is it important?", means objectives would be those objectives for which a clear reason relative to fundamental objectives appears. If no clear reason other than "It just is" appear, the objective probably should be a fundamental objective. Available alternatives are the bottom level of the hierarchy, measured on all objectives immediately superior. If alternative performance on an objective is not measurable, Keeney suggests dropping that objective. Value judgments are required for fundamental objectives, and judgments about facts required for means-ends objectives.



Decision makers should not settle for those alternatives that are thrust upon them. The conventional solution process is to generate alternative solutions to a problem, and then focus on objectives. This framework tends to suppose an environment where decision makers are powerless to do anything but choose among given alternatives. It is suggested that a more fruitful approach would be for decision makers to use objectives to create alternatives, based on what the decision makers would like to achieve, and why objectives are important.

Hierarchy Development Process

Hierarchies can be developed in two basic manners: top-down or bottom-up. The most natural approach is to start at the top, identifying the decision maker's fundamental objective, and developing subelements of value, proceeding downward until all measures of value are included (weeding out redundancies and measures that do not discriminate among available alternatives). At the bottom of the hierarchy, available alternatives can be added. It is at this stage that Keeney (1992) suggested designing new and better alternatives. Keeney et al. suggested the following phases in employing the top-down approach[5]:

1. Ask for overall values
2. Explain the meanings of initial value categories and interrelationships
   WHAT IS MEANT by this value?
   WHY IS THIS VALUE IMPORTANT?
   HOW DO AVAILABLE OPTIONS AFFECT attaining this value?
3. Get a list of concerns – as yet unstructured

The aim of this approach is to gain as wide a spectrum of values as possible. Once they are attained, then the process of weeding and combining can begin.

Neiger et al. applied Keeney's value-focused approach to supply chain risk identification.[6] Here we will present our view of value-focused analysis to a representative supply chain risk situation. We hypothesize a supply chain participant considering location of a plant to produce products for a multinational retailer. We can start looking for overall values, using the input from published sources given in Table 7.1 The first focus is on the purpose of the business – the product. Product characteristics of importance include its quality, meeting specifications, cost, and delivery. In today's business environment, we argue that service is part of the product. We represent that in our hierarchy with the concept of manufacturability and deliverability to consumer (which reflects life cycle value to the customer). The operation of the supply chain is considered next, under the phrase "management," which reflects the ability of the supply chain to communicate, and to be agile in response to changes. There are also external risks, which we cluster into the three areas of political (regulation, as well as war and terrorism), economic (overall economic climate as well as the behavior of the specific market being served), and natural disaster. Each of these hierarchical elements can then be used to identify specific risks for a given supply chain situation. We use those identified in Table 7.1 to develop a value hierarchy.

Table 7.1 Value hierarchy for supply chain risk

Top level	Second level	Third level
Product	Quality	
	Cost	Price
		Investment required
		Holding cost/service level tradeoff
	On-time delivery	
Service	Manufacturability	Outsourcing opportunity cost/risk tradeoff
		Ability to expand production
		New technology breakthroughs
		Product obsolescence
	Deliverability	Transportation system
		Insurance cost
Management	Communication	IS breakdown
		Distorted information leading to bullwhip effect
		Forecast accuracy
		Integration
		Viruses/bugs/hackers
	Flexibility	Agility of sources
		Ability to replace sources as needed
	Safety	Plant disaster
	Labor	Risk of strikes, disputes
Political	Government	Customs and regulations
	War and terrorism	
Economic	Overall economy	Economic downturn
		Exchange rate risk
	Specific regional economy	Labor cost influence
		Changes in competitive advantage
	Specific market	Price fluctuation
		Customer demand volatility
		Customer payment
Natural disaster		Uncontrollable disaster
		Diseases, epidemics

The next step in multiple attribute analysis is to generate the alternatives. There are a number of decisions that might be made, to include vendor selection, plant siting, information system selection, or the decision to enter specific markets by region or country. For some of these, there may be binary decisions (enter a country's market or not), or there might be a number of variants (including different degrees of entering a specific market). In vendor selection and in plant siting, there may be very many alternatives. Usually, multiple attribute analysis focuses on two to seven alternatives that are selected as most appropriate through some screening process. Part of the benefit of value analysis is that better alternatives may be designed as part of the hierarchical development, seeking better solutions performing well on all features.

Suggestions for Cases Where Preferential Independence Is Absent

Keeney (1992) suggested that if an independence assumption is found to be inappropriate, either a fundamental objective has been overlooked or means objectives are beings used as fundamental objectives. Therefore, identification of the absence of independence should lead to greater understanding of the decision maker's fundamental objectives.

Multiattribute Analysis

The next step of the process is to conduct multiattribute analysis. There are a number of techniques that can be applied.[7] Multiattribute utility theory (MAUT) can be supported by software products such as Logical Decision, which are usually applied in more thorough and precise analyses. The simple multiattribute rating theory (SMART)[8] can be used with spreadsheet support, and is usually the easiest method to use. Analytic hierarchy process can also be applied, as was the case in all of the cases applying multiple objective analysis. Expert Choice software is available, but allows only seven branches, so is a bit more restrictive than MAUT, and much more restrictive than SMART. Furthermore, the number of pairwise comparisons required in AHP grows enormously with the number of branches. Still, users often are willing to apply AHP and feel confident in its results.[9] Here we will demonstrate using SMART for a decision involving site selection of a plant within a supply chain.

The SMART Technique

Edwards proposed a ten step technique. Some of these steps include the process of identifying objectives and organization of these objectives into a hierarchy. Guidelines concerning the pruning of these objectives to a reasonable number were provided.

Step 1: Identify the person or organization whose utilities are to be maximized. Edwards argued that MAUT could be applied to public decisions in the same manner as was proposed for individual decision making.

Step 2: Identify the issue or issues. Utility depends on the context and purpose of the decision.

Step 3: Identify the alternatives to be evaluated. This step would identify the outcomes of possible actions, a data gathering process.

Step 4: Identify the relevant dimensions of value for evaluation of the alternatives. It is important to limit the dimensions of value to those that are important for this particular decision. This can be accomplished by restating and combining goals, or by omitting less important goals. Edwards argued that it was not necessary to have a complete list of goals. If the weight for a particular goal is quite low, that goal need not be included. There is no precise range of goals for all decisions. However, eight goals was considered sufficiently large for most cases, and fifteen too many.

Step 5: Rank the dimensions in order of importance. For decisions made by one person, this step is fairly straightforward. Ranking is a decision task that is easier than developing weights, for instance. This task is usually more difficult in group environments. However, groups including diverse opinions can lead to a more thorough analysis of relative importance, as all sides of the issue are more likely to be voiced. An initial discussion could provide all group members with a common information base. This could be followed by identification of individual judgments of relative ranking.

Step 6: Rate dimensions in importance, preserving ratios. The least important dimension would be assigned an importance of 10. The next-least-important dimension is assigned a number reflecting the ratio of relative importance to the least important dimension. This process is continued, checking implied ratios as each new judgment is made. Since this requires a growing number of comparisons, there is a very practical need to limit the number of dimensions (objectives). Edwards expected that different individuals in the group would have different relative ratings.

Step 7: Sum the importance weights, and divide each by the sum. This step allows normalization of the relative importances into weights summing to 1.0.

Step 8: Measure the location of each alternative being evaluated on each dimension. Dimensions were classified into the groups: subjective, partly subjective, and purely objective. For subjective dimensions, an expert in this field would estimate the value of an alternative on a 0–100 scale, with 0 as the minimum plausible value and 100 the maximum plausible value. For partly subjective dimensions, objective measures exist, but attainment values for specific alternatives must be estimated. Purely objective dimensions can be measured. Raiffa advocated identification of utility curves by dimension.[10] Edwards proposed the simpler expedient of connecting the maximum plausible and minimum plausible values with a straight line.[11] It was argued that the straight line approach would provide an acceptably accurate approximation.

Step 9: Calculate utilities for alternatives. $U_j = \Sigma_k w_k u_{jk}$ where U_j is the utility value for alternative j, w_k is the normalized weight for objective k, and u_{jk} is the scaled value for alternative j on dimension k. $\Sigma_k w_k = 1$. The w_k values were obtained from Step 7 and the u_{jk} values were generated in Step 8.

Step 10: Decide. If a single alternative is to be selected, select the alternative with maximum U_j. If a budget constraint existed, rank order alternatives in the order of U_j/C_j where C_j is the cost of alternative j. Then alternatives are selected in order of highest ratio first until the budget is exhausted.

Plant Siting Decision

Assume that a supply chain vendor is considering sites for a new production facility. Management has considered the factors that they feel are important in this decision (the criteria):

- Acquisition and building cost
- Expected cost per unit
- Work force ability to produce quality product
- Work force propensity for labor dispute
- Transportation system reliability
- Expandability
- Agility to changes in demand
- Information system linkage
- Insurance structure
- Tax structure
- Governmental stability
- Risk of disaster

Each of these factors need to be measured in some way. If possible, objective data would be preferred, but often subjective expert estimates are all that is available. The alternatives need to be identified as well. There are an infinite number of sites. But the number considered is always filtered down to a smaller number. Here we will start with ten options. Each of them has estimates performances on each of the 12 criteria listed.

Location	A&B	UnitC	Quality	Labor	Trans	Expand
Alabama	$20 m	$5.50	High	Moderate	0.30	Good
Utah	$23 m	$5.60	High	Good	0.28	Poor
Oregon	$24 m	$5.40	High	Low	0.31	Moderate
Mexico	$18 m	$3.40	Moderate	Moderate	0.25	Good
Crete	$21 m	$6.20	High	Low	0.85	Poor
Indonesia	$15 m	$2.80	Moderate	Moderate	0.70	Fair
Vietnam	$12 m	$2.50	Good	Good	0.75	Good
India	$13 m	$3.00	Good	Good	0.80	Good
China #1	$17 m	$3.10	Good	Good	0.60	Fair
China #2	$15 m	$3.20	Good	Good	0.55	Good

Location	Agility	IS link	Insurance	Tax	Govt	Disaster
Alabama	2 mos	Very good	$400	$1,000	Very good	Hurricane
Utah	3 mos	Very good	$350	$1,200	Very good	Drought
Oregon	1 mo	Very good	$450	$1,500	Good	Flood
Mexico	4 mos	Good	$300	$1,800	Fair	Quake

(continued)

Location	Agility	IS link	Insurance	Tax	Govt	Disaster
Crete	5 mos	Good	$600	$3,500	Good	Quake
Indonesia	3 mos	Poor	$700	$800	Fair	Monsoon
Vietnam	2 mos	Good	$600	$700	Good	Monsoon
India	3 mos	Very good	$700	$900	Very good	Monsoon
China #1	2 mos	Very good	$800	$1,200	Very good	Quake
China #2	3 mos	Very good	$500	$1,300	Very good	Quake

Each of the choices involves some tradeoff. With twelve criteria, it will be rare that one alternative (of the final set of filtered choices) will dominate another, meaning that it is at least as good or better on all criteria measures, and strictly better on at least one criterion.

Each measure can now be assigned a value score on a 0–1 scale, with 0 being the worst performance imaginable, and 1 being the best performance imaginable. This reflects the decision maker's perception, a subjective value. For our data, a possible set of values could be:

Location	A&B	UnitC	Quality	Labor	Trans	Expand
Alabama	0.60	0.40	0.90	0.30	0.90	1.0
Utah	0.30	0.35	0.90	0.80	0.95	0
Oregon	0.10	0.45	0.90	0.10	0.86	0.5
Mexico	0.70	0.80	0.40	0.30	1.00	1.0
Crete	0.50	0.20	0.90	0.10	0.30	0
Indonesia	0.80	0.90	0.40	0.30	0.55	0.3
Vietnam	0.90	0.95	0.60	0.80	0.50	1.0
India	0.85	0.87	0.60	0.80	0.40	1.0
China #1	0.75	0.85	0.60	0.80	0.60	0.3
China #2	0.80	0.83	0.60	0.80	0.70	1.0

Location	Agility	IS link	Insurance	Tax	Govt	Disaster
Alabama	0.8	1.0	0.70	0.80	1.0	0.5
Utah	0.6	1.0	0.80	0.70	1.0	0.9
Oregon	1.0	1.0	0.60	0.60	0.8	0.8
Mexico	0.4	0.7	1.00	0.40	0.4	0.4
Crete	0.2	0.7	0.50	0.00	0.8	0.3
Indonesia	0.6	0	0.30	0.90	0.4	0.7
Vietnam	0.8	0.7	0.50	1.00	0.8	0.7
India	0.6	1.0	0.30	0.85	1.0	0.7
China #1	0.8	1.0	0.10	0.70	1.0	0.8
China #2	0.6	1.0	0.55	0.65	1.0	0.4

Note that for the Disaster criterion, specifics for each locale can lead to different ratings for the same major risk category.

The SMART method now needs to identify relative weights for the importance of each criterion in the opinion of the decision maker or decision making group. This process begins by sorting the criteria by importance. One possible ranking:

- Work force ability to produce quality product
- Expected cost per unit
- Risk of disaster
- Agility to changes in demand
- Transportation system reliability
- Expandability
- Governmental stability
- Tax structure
- Insurance structure
- Acquisition and building cost
- Information system linkage
- Work force propensity for labor dispute

The SMART method proceeds by assigning the most important criterion a value of 1.0, and then assessing relative importance by considering the proportional worth of moving from the worst to the best on the most important criterion (quality) and moving from the worst to the best on the criterion compared to it. For instance, the decision maker might judge moving from the worst possible unit cost to the best possible unit cost to be 0.8 as important as moving from the worst possible quality to the best possible quality. We assume the following ratings based on this procedure:

Criterion		Rating	Proportion
Work force ability to produce quality product	Quality	1.00	0.167
Expected cost per unit	UnitC	0.80	0.133
Risk of disaster	Disaster	0.70	0.117
Agility to changes in demand	Agility	0.65	0.108
Transportation system reliability	Trans	0.60	0.100
Expandability	Expand	0.58	0.097
Government stability	Govt	0.40	0.067
Tax structure	Tax	0.35	0.058
Insurance structure	Insurance	0.32	0.053
Acquisition and building cost	A&B	0.30	0.050
Information system linkage	IS link	0.20	0.033
Work force propensity for labor dispute	Labor	0.10	0.017

Proportion is obtained by dividing each rating by the sum of ratings (6.00). Overall value for each alternative site can then be ranked by the sumproduct of criterion relative importances times the matrix of scores on criteria.

Location	A&B	UnitC	Quality	Labor	Trans	Expand	Agility	IS link	Insurance	Tax	Govt	Disaster
Weight	0.05	0.133	0.167	0.017	0.1	0.097	0.108	0.033	0.053	0.058	0.067	0.117
Alabama	0.6	0.4	0.9	0.3	0.9	1	0.8	1	0.7	0.8	1	0.5
Utah	0.3	0.35	0.9	0.8	0.95	0	0.6	1	0.8	0.7	1	0.9
Oregon	0.1	0.45	0.9	0.1	0.86	0.5	1	1	0.6	0.6	0.8	0.8
Mexico	0.7	0.8	0.4	0.3	1	1	0.4	0.7	1	0.4	0.4	0.4
Crete	0.5	0.2	0.9	0.1	0.3	0	0.2	0.7	0.5	0	0.8	0.3
Indonesia	0.8	0.9	0.4	0.3	0.55	0.3	0.6	0	0.3	0.9	0.4	0.7
Vietnam	0.9	0.95	0.6	0.8	0.5	1	0.8	0.7	0.5	1	0.8	0.7
India	0.85	0.87	0.6	0.8	0.4	1	0.6	1	0.3	0.85	1	0.7
China #1	0.75	0.85	0.6	0.8	0.6	0.3	0.8	1	0.1	0.7	1	0.8
China #2	0.8	0.83	0.6	0.8	0.7	1	0.6	1	0.55	0.65	1	0.4

This analysis ranks the alternatives as follows:

Rank	Site	Score
1	Vietnam	0.762
2	Alabama	0.754
3	India	0.721
4	China #2	0.710
5	Oregon	0.706
6	China #1	0.679
7	Utah	0.674
8	Mexico	0.626
9	Indonesia	0.557
10	Crete	0.394

This indicates a close result for Vietnam and Alabama, with the first 7 sites all reasonably close as well. There are a couple of approaches. More detailed comparisons might be made between Vietnam and Alabama. Another approach is to look at characteristics that these alternatives were rated low on, with the idea that maybe the site's characteristics could be improved.

Conclusions

Structuring of a value hierarchy is a relatively subjective activity, with a great deal of possible latitude. It is good to have a complete hierarchy, including everything that could be of importance to the decision maker. However, this yields unworkable analyses. Hierarchies should focus on those criteria that are important in discriminating among available alternatives. The key to hierarchy structuring is to identify those criteria that are most important to the decision maker, and that will help the decision maker make the required choice.

This chapter presented the value-focused approach of Keeney, and the SMART method. These were demonstrated in the context of the supply chain risk management decision of selecting a plant location for production of a component. The methods apply for any decision involving multiple criteria.

Notes

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Chapter 8
Examples of Supply Chain Decisions Trading Off Criteria

We encountered five recent cases in supply chain risk management that applied analytic hierarchy process (AHP) models. This approach can yield equivalent results from simple multiattribute utility models, a linear form of multiattribute utility theory. In this chapter we review these four cases, taking the original AHP input data and constructing a SMART model, an implementation of value analysis.

These cases were usually applied to evaluate alternative suppliers, either relatively as sources of various types of risk, or in a selection decision. One case, by Gaudenzi and Borghesi, applied AHP in a different mode, to assess a risk scorecard for organizational departments.

Case 1: Blackhurst et al. (2008)

This study focused on a method to identify specific areas of risk by product and by supplier.[1] They used multicriteria analysis, but not with the intent of selecting suppliers, but rather identifying degree of risk, using heat graphs.[2] However, they provided data that would be applicable to supplier selection considering risks. First, they gave a list of criteria. Based on the data provided in their paper, we can infer the following risks, ordered by importance:

Risk	Rank	Based on 1st	Weight
Defects/million parts	1	100.0	0.18
Ease of problem resolution	2–3	83.3	0.15
Timeliness of corrective action	2–3	83.3	0.15
Fire	4	66.7	0.12
Product complexity	5	50.0	0.09
Labor availability	6–7	33.3	0.06
Supplier bankruptcy	6–7	33.3	0.06
Labor dispute	8–10	22.2	0.04
Political issues	8–10	22.2	0.04
War and terrorism	8–10	22.2	0.04
Value of product	11	16.7	0.03

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Risk	Rank	Based on 1st	Weight
Earthquake	12–13	11.1	0.02
Flood	12–13	11.1	0.02
Total		555.4	1.00

Scores for each supplier on each criterion are given below, along with resultant valuescores.

Criteria	Weights	Supplier1	Supplier2	Supplier3	Supplier4
Defects/million	0.18	0.700	0.267	0.850	**0.900**
Ease of resolution	0.15	0.800	0.214	**0.900**	0.850
Product complexity	0.09	0.800	0.761	0.700	**0.850**
Timeliness to correct	0.15	0.800	0.169	**0.850**	**0.850**
Product value	0.03	0.700	0.686	0.650	**0.750**
Earthquake	0.02	0.850	0.650	**0.950**	0.350
Fire	0.12	**0.850**	0.200	0.300	0.700
Flood	0.02	**0.950**	0.650	0.800	0.600
Labor availability	0.06	**0.850**	0.300	0.800	0.650
Labor dispute	0.04	**0.800**	0.150	0.650	0.750
Political issues	0.04	0.800	0.400	**0.850**	0.600
Supplier bankruptcy	0.06	**0.950**	0.900	0.650	0.650
War and terrorism	0.04	**0.750**	0.400	**0.750**	0.700

Note that we are using the data for a different purpose than Blackhurst et al. We are demonstrating how the SMART multiattribute system could be applied. Supplier1 is best on a number of disaster factors, to include fire, flood, labor, supplier bankruptcy, and war and terror. Supplier4 is best on four of the quality factors, while Supplier3 is best on three. In this data, Supplier1 dominates Supplier2 (it is better on all 13 criteria), implying that Supplier2 could be rejected. In the Blackhurst et al. context, each supplier provided different products, so that Supplier2 would not be dominated. In our example, this yields the following scores and implied rankings of suppliers:

Supplier	Score	Rank
Supplier1	0.799	1
Supplier4	0.779	2
Supplier3	0.746	3
Supplier2	0.355	4

Note that Supplier1, Supplier3 and Supplier4 all score relatively high, and it would be prudent to keep all three under consideration. Supplier2 would be probably be eliminated if the decision were to select one (or more) suppliers.

Value Analysis

Thus far we have demonstrated conventional multicriteria decision analysis, applying the SMART method. That includes value analysis development of the hierarchy. (In SMART, the hierarchy focuses on the bottom level of criteria – value analysis goes through the steps of developing a hierarchy, which the original Blackhurst et al. article presented.) The value analysis approach would now focus on improvement of existing alternatives. Here Supplier2 is clearly inferior to the other three alternatives, and might be discarded from consideration. There are two approaches that can be taken. First, if the scores are very close, additional criteria that might differentiate among them might be sought. The second approach would be to try to improve existing alternatives, either by broadening the search to additional suppliers, or to seek actions that would make existing supplier performance better on criteria where their scores were weak.

With respect to consideration of criteria, those criteria where alternatives all do equally well might be discarded, as they won't discriminate among the alternatives. In this case, all criteria have at least some variance in scores across the three top alternatives.

The second approach would focus on improving existing performance on criteria (if this is possible to do). The relative performance of the alternatives Supplier1, Supplier3 and Supplier4 can be analyzed to focus on areas where they might be improved.

Supplier1 is quite strong on the less important criteria, but slightly weaker on those criteria given high weights. Their quality as measured in defects/million parts is where they have the weakest relative performance. They appear to need to improve their production processes to improve (although they currently have the highest value score).

Supplier3 ranked third, despite being the best on the production-related criteria that were weighted highly. They had a slight disadvantage to Supplier4 in defects, and more of a disadvantage to the other two in product complexity and product value. They were rated low on exposure to fire, and had slight disadvantages with respect to labor. They might not be able to do much in some of these areas, but it appears that if they want to be more favorably considered, they need to improve product design and quality.

Supplier4 did quite well in terms of product, but was exposed to more external risks. Relocation may or may not be feasible, but they might consider that is possible. Their labor situation was a relative disadvantage as well as their political situation.

Case 2: Wu et al. (2006)

This study applied an enhanced AHP model for inbound supply risk analysis. Two suppliers were compared on 18 risk factors.[3] The AHP analysis was applied, but could be replicated by the following SMART rankings and relative assessments of importance:

Risk	Rank	Based on 1st	Weight
Cost	1	100	0.251
Quality	2	94	0.236
On-time delivery	3	81	0.203
Continuity of supply	4	51	0.128
Engineering/production	5	17	0.043
Second tier supplier	6	13	0.033
Demand	7	12	0.030
Internal legal issues	8	11	0.028
Natural/man-made disasters	9	10	0.025
Politics/economics	10	10	0.025
Total		399	

The following table shows scores for the two suppliers being evaluated. The original paper (Wu et al.) only provided supplier risk scores for the first ten criteria, so that is all we use in this demonstration. (In Wu et al., high scores represented risk – here we invert so high scores infer preferability.)

Criteria	Weight	Supplier1	Supplier2
Cost	0.251	0.801	0.801
Quality	0.236	0.903	0.701
Delivery	0.203	0.804	0.602
Continuity	0.128	0.907	0.507
Engr/prod	0.043	0.623	0.522
SecondTier	0.033	0.731	0.631
Demand	0.030	0.929	0.612
IntLegal	0.028	0.923	0.923
NaturalDis	0.025	0.627	0.710
Pol/econ	0.025	0.917	0.917
Value		0.84	0.68

The value score can be used to rank suppliers. Here Supplier1 is clearly better than Supplier2, as in Wu et al.

Value Analysis

As in all of these cases, the original article presented hierarchical development, while we focus on the SMART analysis which focuses on the bottom level criteria that constitute the value function. Wu et al. focused on only two supplier sources, and therefore a number of criteria had equivalent scores meaning that they don't discriminate among the alternatives. Cost, Internal legal issues, and Politics/Economics scores were the same for both alternatives, and further analysis might delete these factors. However, if the analysis was to be applied in the future, it would not be appropriate to delete these factors.

The choice here is pretty clear. Supplier1 has a value score advantage of 0.84–0.68 for Supplier2. While final choice should be reserved for the decision maker, if the analysis accurately reflected decision maker preference, Supplier1 would be a clear choice. This is because of relative advantages in quality, delivery, continuity, and demand, with slighter advantages in engineering/production, and second tier supplier relationships. Supplier2 has a relative advantage only with respect to disasters. Thus the inference is that Supplier1 overcomes location disadvantages by much better product features.

Case 3: Kull and Talluri (2008)

This study used AHP to evaluate relative supplier ability to respond to risks.[4] The results were then fed into a goal programming model to select the preferred supplier from three, each of which had some aspect of risk where they were superior. Five general risk categories were identified, each of which consisted of multiple aspects.

Risk	Category	Rank	Based on 1st	Weight
Quality management	Quality	1	100	0.342
Reliable material availability	Delivery	2	72.8	0.249
Reliable cycle time	Delivery	3	61.2	0.209
Protection against natural disaster	Delivery	4	19.9	0.068
Excess capacity	Delivery	5	11.6	0.040
Legal/environmental control	Quality	6	11.1	0.038
Power in the relationship	Cost	7	5.2	0.018
Flexibility in processes	Flexibility	8	3.4	0.012
Cost management capabilities	Cost	9	2.6	0.009
Stable supply market	Confidence	10	2.1	0.007
Information systems	Confidence	11	0.7	0.002
Good relations/communications	Confidence	12	0.7	0.002
Research capabilities	Flexibility	13	0.7	0.002
Stable currency	Cost	14	0.4	0.001
Total			292.4	

Scores for each of 14 aspects were provided for each supplier (Supplier A, Supplier B, Supplier C). These scores were based on AHP, and thus relative, with no evidence of the ideal. We assume the highest score to be ideal here (assigned a value of 1.0), with other scores assigned proportionately.

Risk	Weight	Supplier A	Supplier B	Supplier C
Excess capacity	0.040	**1.0**	0.50	0.25
Reliable material availability	0.249	0.33	**1.0**	0.33
Reliable cycle time	0.209	**1.0**	0.33	**1.0**
Protection against natural disaster	0.068	**1.0**	0.33	0.33
Cost management capabilities	0.009	0.33	0.33	**1.0**
Power in the relationship	0.018	**1.0**	0.33	**1.0**
Stable currency	0.001	1.0	1.0	1.0
Quality management	0.342	1.0	1.0	1.0
Legal/environmental control	0.038	**1.0**	0.33	**1.0**
Research capabilities	0.002	1.0	1.0	1.0
Flexibility in processes	0.012	**1.0**	0.175	0.413
Information systems	0.002	0.438	0.109	**1.0**
Stable supply market	0.007	**1.0**	**1.0**	0.33
Good relations/communications	0.002	**1.0**	0.33	**1.0**
Final score		0.825	0.737	0.746

In this case, Supplier A measures the best, despite disadvantages on its ability to deal with risks in material availability, the criterion with the heaviest weight where alternative suppliers had differing scores. Supplier A made up much of this initial disadvantage by better relative score on reliable cycle time. Given that we forced the best score to be 1.0 for each criterion, each supplier's final score can be viewed as proportional to ideal.

Value Analysis

In this case, there were clear distinguishing performance scores, and each of the three candidate suppliers had relative advantages.

Some criteria didn't matter in this specific decision (stable currency, quality management, research capabilities) because all alternatives had the same performance score. Interestingly, these include the top ranked and lowest ranked of the 14 criteria, so this assessment demonstrates that it is not a matter of importance, but context.

Supplier A had the highest value score, despite disadvantage on material availability, cost management, and information systems. These areas might be focuses of negotiations for improvement if circumstances permitted.

Supplier C was not too far behind Supplier A, but was at disadvantage with respect to protection against natural disaster, excess capacity, process flexibility, and supply market stability. Probably on relocation could overcome risks in the form of natural disaster (and supply market stability), and expensive investment might be required to improve capacity limitations. But process improvement might make Supplier C more competitive.

Supplier B was strong in terms of material availability and supply market stability. However, they were relatively weak on 8 other criteria with respect to Supplier A. They had the weakest information system, and were also weak on process flexibility, which look like good places to start for Supplier B to improve its competitiveness.

Case 4: Schoenherr et al. (2008)

The decision in this case was to consider five variants of outsourcing[5]:

1. Sourcing finished goods from Mexico
2. Sourcing finished goods from China
3. Sourcing parts from China and assembling in the US
4. Sourcing parts from China, assembling in a Mexican Maquiladora without investment
5. Sourcing parts from China, assembling in a Mexican Maquiladora with investment

The decision involved 17 criteria:

Risk factor	Sub obj	Main obj	Rank	Relative	Weight
Product cost	Cost	Product	1	100	0.256
Product defect rate	Quality	Product	2	96.1	0.246
Order fulfillment risk	Service	Partner	3	25.4	0.065
Transportation risk		Environment	4	24.6	0.063
ANSI compliance	Quality	Product	5	24.2	0.062
Competitor cost	Cost	Product	6	19.9	0.051
Supplier fulfillment risk	Service	Partner	7	19.9	0.051
On-time/budget delivery	Service	Partner	8	19.9	0.051
Logistics risk	Service	Partner	9	16.8	0.043
Sovereign risk		Environment	10	8.6	0.022
Wrong partner risk	Mngt capabilities	Partner	11	8.2	0.021
Overseas risk	Mngt capabilities	Partner	12	8.2	0.021
Supplier risk	Mngt capabilities	Partner	13	7.8	0.020
Demand risk	Service	Partner	14	3.9	0.010
Supplier management	Mngt capabilities	Partner	15	3.125	0.008
Natural disaster/terrorism		Environment	16	3.125	0.008
Engineering and innovation	Mngt capabilities	Partner	17	0.78	0.002
				390.53	1.0

The matrix of scores for each criterion by option are given below, along with calculation of overall value score. Again, input data was relative, from AHP, and was set to the ideal by giving the maximum score a value of 1.0, and all others scaled proportionally.

Risk factor	Weight	FG-Mex	FG-Chi	Parts Chi, US assy	Parts Chi, Maq no invest	Parts Chi, Maq w/invest
Product cost	0.256	0.25	1.0	0.22	0.94	0.44
Product defect rate	0.246	0.73	1.0	0.62	0.73	0.85
Order fulfillment risk	0.065	0.37	1.0	0.93	0.47	0.53
Transportation risk	0.063	1.0	0.59	0.38	0.33	0.31
ANSI compliance	0.062	1.0	1.0	1.0	1.0	1.0
Competitor cost	0.051	0.09	1.0	0.26	0.49	0.53
Supplier fulfillment risk	0.051	0.25	0.33	0.53	1.0	0.72
On-time/budget delivery	0.051	1.0	0.28	0.31	0.09	0.17
Logistics risk	0.043	1.0	0.49	0.22	0.16	0.16
Sovereign risk	0.022	1.0	0.54	0.54	0.20	0.20
Wrong partner risk	0.021	1.0	1.0	0.63	1.0	0.19
Overseas risk	0.021	0.46	0.125	1.0	0.125	0.23
Supplier risk	0.020	0.13	0.54	1.0	0.28	0.54
Demand risk	0.010	1.0	0.125	0.525	0.25	0.575
Supplier management	0.008	0.57	0.29	1.0	0.14	0.24
Natural disaster/terrorism	0.008	1.0	0.26	0.35	0.13	0.13
Engineering and innovation	0.002	0.41	1.0	0.85	0.41	1.0
Value score		0.583	0.823	0.505	0.660	0.552

These are proportional to the normalized additive scores reported to Schoenherr et al., and indicate an advantage for the option of obtaining finished goods from China. China had a big advantage in having the best performance on the two most important criteria of product cost and product quality (as measured by defect rate). It was weakest on the factors of overseas risk, demand risk, natural disaster/terrorism, on-time/budget delivery, and supplier management. The first and third can probably best be dealt with through insurance (the cost of which should be incorporated in product cost, possibly revising ratings). Demand risk might be dealt with through hedging mechanisms. Actions might be taken to improve on-time delivery and supplier management through training or business process reengineering.

Value Analysis

This example provided more concrete alternatives, making the comparison potentially clearer. The clear winner was to outsource production of finished goods to

China. Of course, there are many Chinese manufacturers, so a more focused analysis might be required to select specific vendors.

All of the options considered had equivalent scores on ANSI compliance. That does not diminish the importance of this criterion, but for this set of alternatives, this factor does not bear on the decision. All other criteria distinguished among the available choices to some degree.

The recommended source had some relative weaknesses. Transportation risk is something that might not be able to be improved a great deal, due to geographic location. This also plays a role in relative scores for most of the other criteria where this alternative had relative disadvantage. But China's relative advantages in cost, quality, and fulfillment performance gave it a strong advantage in this analysis.

The second highest value score came from obtaining parts in China, and assembling in existing facilities in Mexico. The scores indicate relative advantages in reducing supplier fulfillment risk and wrong partner risk. This alternative had the greatest room for improvement in transportation risk management, order fulfillment risk, and on-time delivery. It also scored relatively low on a number of other criteria that had low weights, and thus are less important to improve in this specific decision.

Outsourcing to Mexico was next in value score. This alternative was quite weak in cost, the most important criterion, and average on the second most important criterion of product quality. These clearly would be areas calling for improvement. Constructing the new facility clearly has a high cost impact, giving use of existing Mexican facilities more attractive in this case.

Case 5: Gaudenzi and Borghesi (2006)

This application used AHP in the style of a business scorecard.[6] While the authors gave a good discussion of criteria and its components, the data they provide for relative weights referred only to the top level factors of On-time delivery, completeness, correctness, and damage/defect free products. They also gave examples demonstrating scoring of departments within the organization on each of these four criteria by managerial subjective assessment, as well as using a more metric-driven model. Furthermore, they gave ranges for relative weight importance (which could be used for alternative multicriteria models[7] such as HIPRE).[8]

In this study, data for relative criteria importance was given in ranges. We present the extremes below in development of SMART weights.

Criteria	Mean	Weights	Extreme1	weights	Extreme2	Weights
On-time delivery	100	0.317	100	0.402	50	0.215
Completeness	90	0.286	66	0.265	100	0.429
Correctness	75	0.238	50	0.201	50	0.215
Damage-defect free	50	0.159	33	0.133	33	0.142
	315		249		233	

The last two criteria have fairly consistent weights, so we chose weight of 0.21 for Correctness and 0.14 for Damage-defect free products. The first two had quite a range, as each extreme had a different first selection. Using the maximum weight for the first and subtracting 0.35 as the weight for the third and fourth ranked criteria, weights were generated. Using on-time delivery as the most important criteria yielded a weight for completeness outside the extreme weights, so we raised that weight to 0.29, lowering the weight for on-time delivery to 0.36. No adjustment was necessary to keep weights within range for the set of weights assigning completeness the greatest weight.

Criteria	On-time first	Completeness first
On-time delivery	0.36	0.22
Completeness	0.29	0.43
Correctness	0.21	0.21
Damage-defect free	0.14	0.14

Gaudenzi and Borghesi gave two sets of scores to evaluate risks within their departments. Scores based on managerial input as well as a model used by Gaudenzi and Borghesi are demonstrated with both sets of weights generated above. Scores here are presented in a positivist perspective, with 1.0 representing the best performance. Therefore low resulting scores are associated with the most problematic departments.

The first set of value scores reflect weights emphasizing on-time delivery, with manager subjective scores.

	Weights	Procurement	Warehouse	OrderCycle	Manufact.	Trans.
On-time delivery	0.36	0	0.5	1	0.5	0
Completeness	0.29	0	0.5	1	1	1
Correctness	0.21	1	1	1	1	0.5
Defect free	0.14	0.5	1	1	1	0
Value scores		0.28	0.675	1	0.82	0.395

The scores themselves highlight where risks exist (0 indicates high risk, 0.5 medium level risk). The value scores give something that could be used to assess overall relative performance by department. Order cycle has no problems, so it has to score best. Manufacturing seems to have their risks well under control. Procurement and transportation departments are more troublesome.

The second set uses the same weights, but scores based on model inputs.

	Weights	Procurement	Warehouse	OrderCycle	Manufact.	Trans.
On-time delivery	0.36	0	0	1	0.5	0
Completeness	0.29	0	0	1	1	1

	Weights	Procurement	Warehouse	OrderCycle	Manufact.	Trans.
Correctness	0.21	1	1	0.5	1	0.5
Defect free	0.14	1	0.5	1	1	0
Value scores		0.35	0.28	0.895	0.82	0.395

The implications are similar, except that the warehousing department shows up as facing much more risk.

We can repeat the analysis using weights emphasizing completeness. Using managerial subjective scores:

	Weights	Procurement	Warehouse	OrderCycle	Manufact.	Trans.
On-time delivery	0.22	0	0.5	1	0.5	0
Completeness	0.43	0	0.5	1	1	1
Correctness	0.21	1	1	1	1	0.5
Defect free	0.14	0.5	1	1	1	0
Value scores		0.28	0.675	1	0.89	0.535

This set of weights gives the transport department a better performance rating, but otherwise similar performance to the earlier analysis.

Finally, we use the model scores for weights emphasizing completeness.

	Weights	Procurement	Warehouse	OrderCycle	Manufact.	Trans.
On-time delivery	0.22	0	0	1	0.5	0
Completeness	0.43	0	0	1	1	1
Correctness	0.21	1	1	0.5	1	0.5
Defect free	0.14	1	0.5	1	1	0
Value scores		0.35	0.28	0.895	0.89	0.535

Here the warehouse department appears to face the greatest risk, followed by the procurement department.

The Guadenzi and Borghesi article presents an interesting application of multiple criteria analysis to something akin to business scorecard analysis, extending it to provide a potential departmental assessment of relative degree of risk faced.

Value Analysis

This application differs, because its intent is to provide a balanced scorecard type of model. This can be very useful, and interesting. But value analysis applies only to hierarchical development, because Gaudenzi and Borghesi apply AHP to performance measurement.

Conclusions

The cases presented here all applied multiple criteria models (the last five AHP). This type of model provides a very good framework to describe specific aspects of risk and to assess where they exist, as well as considering their relative performance. The value scores might be usable as a means to select preferred alternatives, but even better, through value analysis, they can direct attention to features that call for the greatest improvement.

Value analysis can provide useful support to decision making by first focusing on hierarchical development. In all five cases presented here, this was accomplished in the original articles. Nonetheless, it is important to consider over-arching objectives, as well as means objectives in light of over-arching objective accomplishment.

We demonstrated two aspects of value analysis in selection decisions. First, if scores on available alternatives are equivalent on a specific criterion, this criterion will not matter for this set of alternatives. However, it may matter if new alternatives are added, or existing alternatives improved.

The second benefit of value analysis is improvement of existing alternatives. The score matrix provides useful comparisons of relative alternative performance.

Finally, if decision makers are not satisfied with existing alternatives, they might seek additional choices through expanding their search or designing them. The criteria with the greatest weights might provide an area of search, and the ideal scores provide a design standard.

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Chapter 9
Simulation of Supply Chain Risk

Supply chains involve many risks, as we have seen. Modeling that risk focuses on probability, a well-developed analytic technique. This chapter addresses basic simulation models involving supply chains, to include inventory modeling (often accomplished through system dynamics) and Monte Carlo simulation of vendor outsourcing decisions.

Inventory Systems

Inventory is any resource that is set aside for future use. Inventory is necessary because the demand and supply of goods usually are not perfectly matched at any given time or place. Many different types of inventories exist. Examples include raw materials (such as coal, crude oil, cotton), semi-finished products (aluminum ingots, plastic sheets, lumber), and finished products (cans of food, computer terminals, shirts). Inventories can also be human resources (standby crews and trainees), financial resources (cash on hand, accounts receivable), and other resources such as airplanes seats.

The basic risks associated with inventories are the risks of stocking out (and thus losing sales), and the counter risk of going broke because excessive cash flow is tied up in inventory. The problem is made interesting because demand is almost always uncertain, driven by the behavior of the market, usually many people making spontaneous purchasing decisions.

Inventories represent a considerable investment for many organizations; thus, it is important that they be managed well. Although many analytic models for managing inventories exist, the complexity of many practical situations often requires simulation.

The two basic inventory decisions that managers face are *how much* to order or produce additional inventory, and *when* to order or produce it. Although it is possible to consider these two decisions separately, they are so closely related that a simultaneous solution is usually necessary. Typically, the objective is to minimize total inventory costs.

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Total inventory cost can include four components: holding costs, ordering costs, shortage costs, and purchasing costs. *Holding costs*, or *carrying costs*, represent costs associated with maintaining inventory. These costs include interest incurred or the opportunity cost of having capital tied up in inventories; storage costs such as insurance, taxes, rental fees, utilities, and other maintenance costs of storage space; warehousing or storage operation costs, including handling, record keeping, information processing, and actual physical inventory expenses; and costs associated with deterioration, shrinkage, obsolescence, and damage. Total holding costs are dependent on how many items are stored and for how long they are stored. Therefore, holding costs are expressed in terms of *dollars associated with carrying one unit of inventory for unit of time.*

Ordering costs represent costs associated with replenishing inventories. These costs are not dependent on how many items are ordered at a time, but on the number of orders that are prepared. Ordering costs include overhead, clerical work, data processing, and other expenses that are incurred in searching for supply sources, as well as costs associated with purchasing, expediting, transporting, receiving, and inspecting. In manufacturing operations, *setup cost* is the equivalent to ordering cost. Set-up costs are incurred when a factory production line has to be shut down in order to reorganize machinery and tools for a new production run. Set-up costs include the cost of labor and other time-related costs required to prepare for the new product run. We usually assume that the ordering or setup cost is constant and is expressed in terms of *dollars per order*.

Shortage costs, or *stock-out costs*, are those costs that occur when demand exceeds available inventory in stock. A shortage may be handled as a *backorder*, in which a customer waits until the item is available, or as a *lost sale*. In either case, a shortage represents lost profit and possible loss of future sales. Shortage costs depend on how much shortage has occurred and sometimes for how long. Shortage costs are expressed in terms of *dollar cost per unit of short item.*

Purchasing costs are what firms pay for the material or goods. In most inventory models, the price of materials is the same regardless of the quantity purchased; in this case, purchasing costs can be ignored. However, when price varies by quantity purchased, called the *quantity discount* case, inventory analysis must be adjusted to account for this difference.

Basic Inventory Simulation Model

Many models contain variables that change continuously over time. One example would be a model of a retail store's inventory. The number of items change gradually (though discretely) over an extended time period; however, for all intents and purposes, they may be treated as continuous. As customer demand is fulfilled, inventory is depleted, leading to factory orders to replenish the stock. As orders are received from suppliers, the inventory increases. Over time, particularly if orders are relatively small and frequent as we see in just-in-time environments, the inventory level can be represented by a smooth, continuous, function.

We can build a simple inventory simulation model beginning with a spreadsheet model as shown in Table 9.1. Model parameters include a holding rate of 0.8 per item per day, an order rate of 300 for each order placed, a purchase price of 90, and a sales price of 130. The decision variables are when to order (when the end of day quantity drops below the reorder point (ROP), and the quantity ordered (Q)). The model itself has a row for each day (here 30 days are modeled). Each day has a starting inventory (column B) and a probabilistic demand (column C) generated from a normal distribution with a mean of 100 and a standard deviation of 10. Demand is made integer. Sales (column D) are equal to the minimum of the starting quantity and demand. End of day inventory (column E) is the maximum of 0 or starting inventory minus demand. The quantity ordered at the end of each day in column F (here assumed to be on hand at the beginning of the next day) is 0 if ending inventory exceeds ROP, or Q if ending inventory drops at or below ROP.

Table 9.1 Crystal ball basic inventory model

	A	B	C	D	E	F	G	H	I	J	K
1	Holdrate	0.8		ROP	140						
2	Orderrate	300		Q	140						
3	Purchase	90					Net	110,359.2		Short	0
4	Sell	130									
5							2,440.8	6,600	277,200	388,050	
6	Day	Start	Demand	Sales	End	Order	Holdcost	Ordercost	Purchase	Revenue	Short
7	1	100	85	85	15	140	12	300	12,600	11,050	0
8	2	155	84	84	71	140	56.8	300	12,600	10,920	0
9	3	211	104	104	107	140	85.6	300	12,600	13,520	0
10	4	247	105	105	142	0	113.6	0	0	13,650	0
11	5	142	104	104	38	140	30.4	300	12,600	13,520	0
12	6	178	116	116	62	140	49.6	300	12,600	15,080	0
13	7	202	105	105	97	140	77.6	300	12,600	13,650	0
14	8	237	94	94	143	0	114.4	0	0	12,220	0
15	9	143	83	83	60	140	48	300	12,600	10,790	0
16	10	200	94	94	106	140	84.8	300	12,600	12,220	0
17	11	246	115	115	131	140	104.8	300	12,600	14,950	0
18	12	271	128	128	143	0	114.4	0	0	16,640	0
19	13	143	107	107	36	140	28.8	300	12,600	13,910	0
20	14	176	110	110	66	140	52.8	300	12,600	14,300	0
21	15	206	102	102	104	140	83.2	300	12,600	13,260	0
22	16	244	96	96	148	0	118.4	0	0	12,480	0
23	17	148	91	91	57	140	45.6	300	12,600	11,830	0
24	18	197	102	102	95	140	76	300	12,600	13,260	0
25	19	235	104	104	131	140	104.8	300	12,600	13,520	0
26	20	271	96	96	175	0	140	0	0	12,480	0
27	21	175	103	103	72	140	57.6	300	12,600	13,390	0
28	22	212	98	98	114	140	91.2	300	12,600	12,740	0
29	23	254	97	97	157	0	125.6	0	0	12,610	0
30	24	157	103	103	54	140	43.2	300	12,600	13,390	0
31	25	194	86	86	108	140	86.4	300	12,600	11,180	0
32	26	248	105	105	143	0	114.4	0	0	13,650	0
33	27	143	89	89	54	140	43.2	300	12,600	11,570	0
34	28	194	106	106	88	140	70.4	300	12,600	13,780	0
35	29	228	89	89	139	140	111.2	300	12,600	11,570	0
36	30	279	84	84	195	0	156	0	0	10,920	0

Profit and shortage are calculated to the right of the basic inventory model. Column G calculates holding cost by multiplying the parameter is cell B2 times the ending inventory quantity for each day, and summing over the 30 days in cell G5. Order costs are calculated by day as $300 if an order is placed that day, and 0 otherwise, with the monthly total ordering cost accumulated in cell H5. Cell I5 calculates total purchasing cost, cell J5 total revenue, and cell H3 calculates net profit considering the value of starting inventory and ending inventory. Column K identifies sales lost (SHORT), with cell K5 accumulating these for the month.

Crystal Ball simulation software allows introduction of three types of special variables. Probabilistic variables (assumption cells in Crystal Ball terminology) are modeled in column C using a normal distribution (CB.Normal(mean, std)). Decision variables are modeled for ROP (cell E1) and Q (cell E2). Crystal Ball allows setting minimum and maximum levels for decision variables, as well as step size. Here we used ROP values of 80, 100, 120, and 140, and Q values of 100, 110, 120, 130 and 140. The third type of variable is a forecast cell. We have forecast cells for net profit (H3) and for sales lost (cell K3).

The Crystal Ball simulation can be set to run for up to 10,000 repetitions for combination of decision variables. We selected 1,000 repetitions. Output is given for forecast cells. Figure 9.1 shows net profit for the combination of an ROP of 140 and a Q of 140.

Tabular output is also provided as in Table 9.2.

Similar output is given for the other forecast variable, SHORT (Fig. 9.2, Table 9.3).

Crystal Ball also provides a comparison over all decision variable values, as given in Table 9.4.

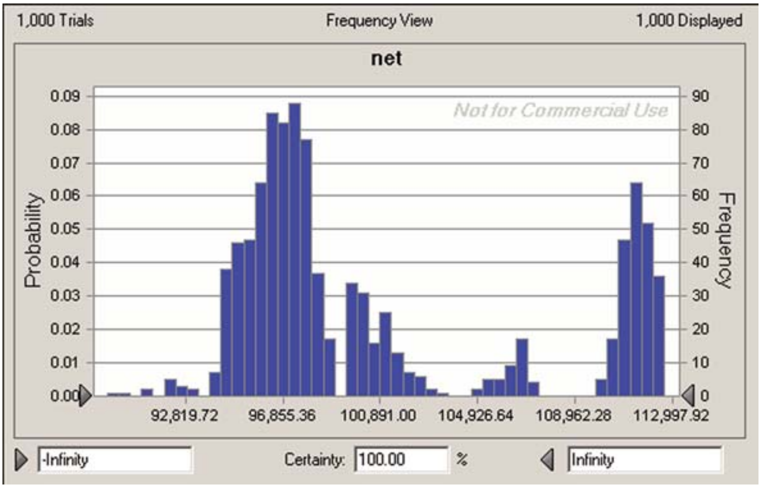


Fig. 9.1 Crystal ball output for net profit ROP 140, Q 140

Table 9.2 Statistical output for net profit ROP 140, Q 140

Forecast: net	
Statistic	Forecast values
Trials	1,000
Mean	100,805.56
Median	97,732.8
Mode	97,042.4
Standard deviation	6,264.80
Variance	39,247,672.03
Skewness	0.8978
Kurtosis	2.21
Coeff. of variability	0.0621
Minimum	89,596.80
Maximum	112,657.60
Mean Std. error	198.11

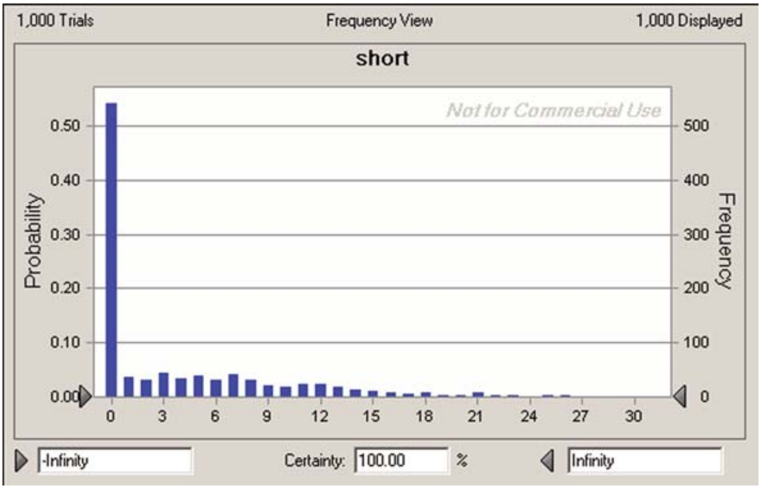


Fig. 9.2 Short for ROP 140, Q 140

The implication here is that the best decision for the basic model parameters would be an ROP of 120 and a Q of 130, yielding an expected net profit of $101,446 for the month. The shortage for this combination had a mean of 3.43 items per day, with a distribution shown in Fig. 9.3. The probability of shortage was 0.4385.

System Dynamics Modeling of Supply Chains

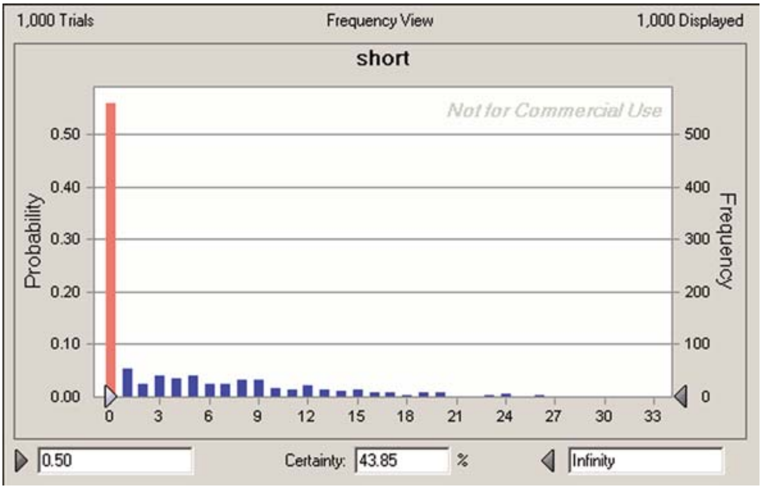
Many models contain variables that change continuously over time. One example would be a model of an oil refinery. The amount of oil moving between various stages of production is clearly a continuous variable. In other models, changes in variables occur gradually (though discretely) over an extended time period;

Table 9.3 Statistical output: ROP 140, Q 140

Forecast: net	
Statistic	Forecast values
Trials	1,000
Mean	3.72
Median	0.00
Mode	0.00
Standard deviation	5.61
Variance	31.47
Skewness	1.75
Kurtosis	5.94
Coeff. of variability	1.51
Minimum	0.00
Maximum	31.00
Mean Std. error	0.18

Table 9.4 Comparative net profit for all values of ROP, Q

Trend Chart Overlay Chart Forecast Chart	Q (100.00)	Q (110.00)	Q (120.00)	Q (130.00)	Q (140.00)	
ROP (80.00)	99,530	99,948	99,918	100,159	101,331	1
ROP (100.00)	99,627	100,701	101,051	101,972	101,512	2
ROP (120.00)	99,519	100,429	100,919	101,446	101,252	3
ROP (140.00)	99,525	99,894	100,586	100,712	100,805	4
	1	2	3	4	5	



0.50 Certainty: 43.85 % Infinity

Fig. 9.3 Short for R = 120, Q = 130

however, for all intents and purposes, they may be treated as continuous. An example would be the amount of inventory at a warehouse in a production-distribution system over several years. As customer demand is fulfilled, inventory is depleted, leading to factory orders to replenish the stock. As orders are received from suppliers, the inventory increases. Over time, particularly if orders are relatively small and frequent as we see in just-in-time environments, the inventory level can be represented by a smooth, continuous, function.

Continuous variables are often called state variables. A continuous simulation model defines equations for relationships among state variables so that the dynamic behavior of the system over time can be studied. To simulate continuous systems, we use an activity-scanning approach whereby time is decomposed into small increments. The defining equations are used to determine how the state variables change during an increment of time. A specific type of continuous simulation is called system dynamics, which dates back to the early 1960s and a classic work by Jay Forrester of M.I.T.[1] System dynamics focuses on the structure and behavior of systems that are composed of interactions among variables and feedback loops. A system dynamics model usually takes the form of an influence diagram that shows the relationships and interactions among a set of variables.

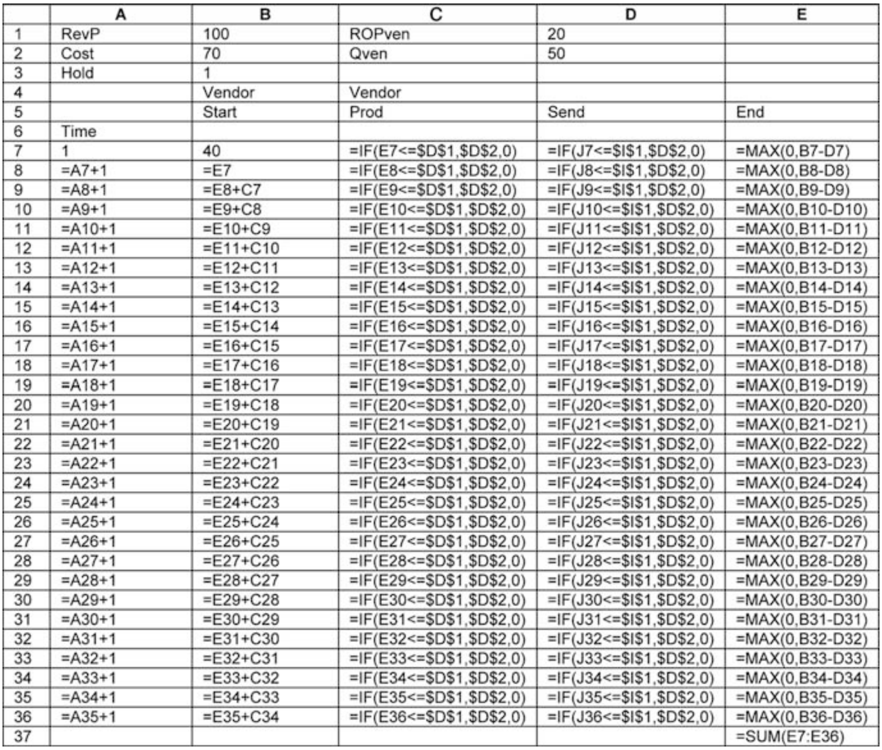
System dynamics models have been widely used to model supply chains, especially with respect to the bullwhip phenomenon,[2] which has to do with the dramatic increase in inventories across supply chains when uncertainty in demand appears. Many papers have dealt with the bullwhip effect through system dynamics models.[3] These models have been used to evaluate lean systems,[4] Kanban systems,[5] JIT and MRP systems,[6] and capacity augmentation of supply chains.[7] They have been used to model push and pull systems.[8] They also have been used to model vendor management inventory and other IT-enhanced systems to improve supply chain management (and reduce risk).[9]

We present a four echelon supply chain model, consisting of a vendor providing raw materials, an assembly operation to create the product, a warehouse, and a set of five retailers. We will model two systems – one a push system, the other pull in the sense that upstream activity depends on downstream demand. We will present the pull system first.

Pull System

The basic model uses a forecasting system based on exponential smoothing to drive decisions to send material down the supply chain. We use EXCEL modeling, along with Crystal Ball software to do simulation repetitions, following Evans and Olson (2001).[10] The formulas for the factory portion of the model are given in Fig. 9.4.

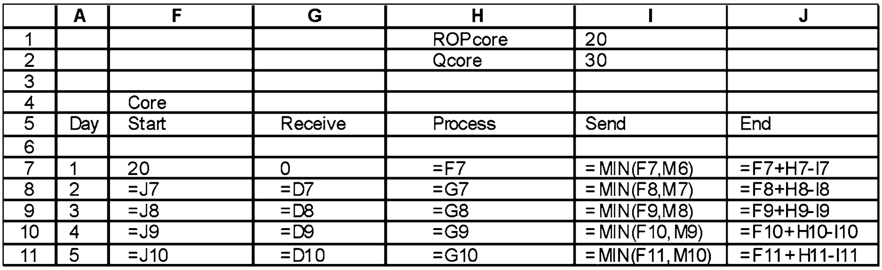
Figure 9.4 models a month of daily activity. Sales of products at retail generate \$100 in revenue for the core organization, at a cost of \$70 per item. Holding costs are \$1 at the retail level (\$0.50 at wholesale, \$0.40 at assembly, \$0.25 at vendors). Daily orders are shipped from each element, at a daily cost of \$1,000 from factory



	A	B	C	D	E
1	RevP	100	ROPven	20	
2	Cost	70	Qven	50	
3	Hold	1			
4		Vendor	Vendor		
5		Start	Prod	Send	End
6	Time				
7	1	40	=IF(E7<=$D$1,$D$2,0)	=IF(J7<=$I$1,$D$2,0)	=MAX(0,B7-D7)
8	=A7+1	=E7	=IF(E8<=$D$1,$D$2,0)	=IF(J8<=$I$1,$D$2,0)	=MAX(0,B8-D8)
9	=A8+1	=E8+C7	=IF(E9<=$D$1,$D$2,0)	=IF(J9<=$I$1,$D$2,0)	=MAX(0,B9-D9)
10	=A9+1	=E9+C8	=IF(E10<=$D$1,$D$2,0)	=IF(J10<=$I$1,$D$2,0)	=MAX(0,B10-D10)
11	=A10+1	=E10+C9	=IF(E11<=$D$1,$D$2,0)	=IF(J11<=$I$1,$D$2,0)	=MAX(0,B11-D11)
12	=A11+1	=E11+C10	=IF(E12<=$D$1,$D$2,0)	=IF(J12<=$I$1,$D$2,0)	=MAX(0,B12-D12)
13	=A12+1	=E12+C11	=IF(E13<=$D$1,$D$2,0)	=IF(J13<=$I$1,$D$2,0)	=MAX(0,B13-D13)
14	=A13+1	=E13+C12	=IF(E14<=$D$1,$D$2,0)	=IF(J14<=$I$1,$D$2,0)	=MAX(0,B14-D14)
15	=A14+1	=E14+C13	=IF(E15<=$D$1,$D$2,0)	=IF(J15<=$I$1,$D$2,0)	=MAX(0,B15-D15)
16	=A15+1	=E15+C14	=IF(E16<=$D$1,$D$2,0)	=IF(J16<=$I$1,$D$2,0)	=MAX(0,B16-D16)
17	=A16+1	=E16+C15	=IF(E17<=$D$1,$D$2,0)	=IF(J17<=$I$1,$D$2,0)	=MAX(0,B17-D17)
18	=A17+1	=E17+C16	=IF(E18<=$D$1,$D$2,0)	=IF(J18<=$I$1,$D$2,0)	=MAX(0,B18-D18)
19	=A18+1	=E18+C17	=IF(E19<=$D$1,$D$2,0)	=IF(J19<=$I$1,$D$2,0)	=MAX(0,B19-D19)
20	=A19+1	=E19+C18	=IF(E20<=$D$1,$D$2,0)	=IF(J20<=$I$1,$D$2,0)	=MAX(0,B20-D20)
21	=A20+1	=E20+C19	=IF(E21<=$D$1,$D$2,0)	=IF(J21<=$I$1,$D$2,0)	=MAX(0,B21-D21)
22	=A21+1	=E21+C20	=IF(E22<=$D$1,$D$2,0)	=IF(J22<=$I$1,$D$2,0)	=MAX(0,B22-D22)
23	=A22+1	=E22+C21	=IF(E23<=$D$1,$D$2,0)	=IF(J23<=$I$1,$D$2,0)	=MAX(0,B23-D23)
24	=A23+1	=E23+C22	=IF(E24<=$D$1,$D$2,0)	=IF(J24<=$I$1,$D$2,0)	=MAX(0,B24-D24)
25	=A24+1	=E24+C23	=IF(E25<=$D$1,$D$2,0)	=IF(J25<=$I$1,$D$2,0)	=MAX(0,B25-D25)
26	=A25+1	=E25+C24	=IF(E26<=$D$1,$D$2,0)	=IF(J26<=$I$1,$D$2,0)	=MAX(0,B26-D26)
27	=A26+1	=E26+C25	=IF(E27<=$D$1,$D$2,0)	=IF(J27<=$I$1,$D$2,0)	=MAX(0,B27-D27)
28	=A27+1	=E27+C26	=IF(E28<=$D$1,$D$2,0)	=IF(J28<=$I$1,$D$2,0)	=MAX(0,B28-D28)
29	=A28+1	=E28+C27	=IF(E29<=$D$1,$D$2,0)	=IF(J29<=$I$1,$D$2,0)	=MAX(0,B29-D29)
30	=A29+1	=E29+C28	=IF(E30<=$D$1,$D$2,0)	=IF(J30<=$I$1,$D$2,0)	=MAX(0,B30-D30)
31	=A30+1	=E30+C29	=IF(E31<=$D$1,$D$2,0)	=IF(J31<=$I$1,$D$2,0)	=MAX(0,B31-D31)
32	=A31+1	=E31+C30	=IF(E32<=$D$1,$D$2,0)	=IF(J32<=$I$1,$D$2,0)	=MAX(0,B32-D32)
33	=A32+1	=E32+C31	=IF(E33<=$D$1,$D$2,0)	=IF(J33<=$I$1,$D$2,0)	=MAX(0,B33-D33)
34	=A33+1	=E33+C32	=IF(E34<=$D$1,$D$2,0)	=IF(J34<=$I$1,$D$2,0)	=MAX(0,B34-D34)
35	=A34+1	=E34+C33	=IF(E35<=$D$1,$D$2,0)	=IF(J35<=$I$1,$D$2,0)	=MAX(0,B35-D35)
36	=A35+1	=E35+C34	=IF(E36<=$D$1,$D$2,0)	=IF(J36<=$I$1,$D$2,0)	=MAX(0,B36-D36)
37					=SUM(E7:E36)

Fig. 9.4 Factory model

to assembler, $700 from assembler to warehouse, $300 from warehouse to retailers. Vendors produce 50 items of material per day if inventory drops to 20 items or less. If not, they do not produce. They send material to the assembly operation if called by that element, which is modeled in Fig. 9.5 (only the first 5 days are shown). Vendor ending inventory is shown in column E, with cell E37 adding total monthly inventory.



	A	F	G	H	I	J
1				ROPcore	20	
2				Qcore	30	
3						
4		Core				
5	Day	Start	Receive	Process	Send	End
6						
7	1	20	0	=F7	= MIN(F7,M6)	=F7+H7-I7
8	2	=J7	=D7	=G7	= MIN(F8,M7)	=F8+H8-I8
9	3	=J8	=D8	=G8	= MIN(F9,M8)	=F9+H9-I9
10	4	=J9	=D9	=G9	= MIN(F10, M9)	=F10+H10-I10
11	5	=J10	=D10	=G10	= MIN(F11, M10)	=F11+H11-I11

Fig. 9.5 Core assembly model

The assembly operation calls for replenishment of 30 units from the vendor whenever their inventory of finished goods drops to 20 or less. Each daily delivery is 30 units, and is received at the beginning of the next day's operations. The assembly operation takes 1 day, and goods are available to send that evening. Column J shows ending inventory to equal what starting inventory plus what was processed that day minus what was sent to wholesale. Figure 9.6 shows the model of the wholesale operation.

The wholesale operation feeds retail demand, which is shown in column L. They feed retailers up to the amount they have in stock. They order from the assembler if they have less than 25 items. If they stock out, they order 20 items plus 70% of what they were unable to fill (this is essentially an exponential smoothing forecast). If they still have stock on hand, the order to fill up to 25 items. Figure 9.7 shows one of the five retailer operations (the other four are identical).

Retailers face a highly variable demand with a mean of 4. They fill what orders they have stock for. Shortfall is measured in column U. They order if their end-of-day inventory falls to 4 or less. The amount ordered is 4 plus 70% of shortfall, up to a maximum of 8 units.

This model is run of Crystal Ball to generate a measure of overall system profit. Here the profit formula is $175 times sales minus holding costs minus transportation

	A	K	L	M	N	O	P
1				WholMin	20		
2				WholMax	25		
3							
4		Whol					
5	Day	Start	Demand	Order	End	Short	Sent
6				0			
7	1	=20	=20	=IF(O7>0,$N$1+INT(0.7*O7),IF(N7>$N$2,0,$N$2-N7))	=K7-P7	=IF(L7>K7,L7-K7,0)	MIN(K7,L7)
8	2	=N7+I7	= T7+Y7+AD7+AI7+AM7	=IF(O8>0,$N$1+INT(0.7*O8),IF(N8>$N$2,0,$N$2-N8))	=K8-P8	=IF(L8>K8,L8-K8,0)	MIN(K8,L8)
9	3	=N8+I8	= T8+Y8+AD8+AI8+AM8	=IF(O9>0,$N$1+INT(0.7*O9),IF(N9>$N$2,0,$N$2-N9))	=K9-P9	=IF(L9>K9,L9-K9,0)	MIN(K9,L9)
10	4	=N9+I9	= T9+Y9+AD9+AI9+AM9	=IF(O10>0,$N$1+INT(0.7*O10),IF(N10>$N$2,0,$N$2-N10))	=K10-P10	=IF(L10>K10,L10-K10,0)	MIN(K10,L10)
11	5	=N10+I10	= T10+Y10+AD10+AI10+AM10	=IF(O11>0,$N$1+INT(0.7*O11),IF(N11>$N$2,0,$N$2-N11))	=K11-P11	=IF(L11>K11,L11-K11,0)	MIN(K11,L11)

Fig. 9.6 Wholesale model

	A	Q	R	S	T	U
1		start	4		order	ROP+.7short
2		rop	4			to Tmax
3		Tmax	8			
4						
5		R1				
6		start	demand	end	order	short
7		=$R$1	=INT(CB.Exponential(0.25))	=MAX(0,Q7-R7)	=IF(S7<=$R$2,4+INT(0.7*U7),IF(S7>$R$3,0,$R$3-S7))	=IF(R7>Q7,R7-Q7,0)
8		=S7+MIN(P7,T7)	=INT(CB.Exponential(0.25))	=MAX(0,Q8-R8)	=IF(S8<=$R$2,4+INT(0.7*U8),IF(S8>$R$3,0,$R$3-S8))	=IF(R8>Q8,R8-Q8,0)
9		=S8+MIN(P8,T8)	=INT(CB.Exponential(0.25))	=MAX(0,Q9-R9)	=IF(S9<=$R$2,4+INT(0.7*U9),IF(S9>$R$3,0,$R$3-S9))	=IF(R9>Q9,R9-Q9,0)
10		=S9+MIN(P9,T9)	=INT(CB.Exponential(0.25))	=MAX(0,Q10-R10)	=IF(S10<=$R$2,4+INT(0.7*U10),IF(S10>$R$3,0,$R$3-S10))	=IF(R10>Q10,R10-Q10,0)
11		=S10+MIN(P10,T10)	=INT(CB.Exponential(0.25))	=MAX(0,Q11-R11)	=IF(S11<=$R$2,4+INT(0.7*U11),IF(S11>$R$3,0,$R$3-S11))	=IF(R11>Q11,R11-Q11,0)

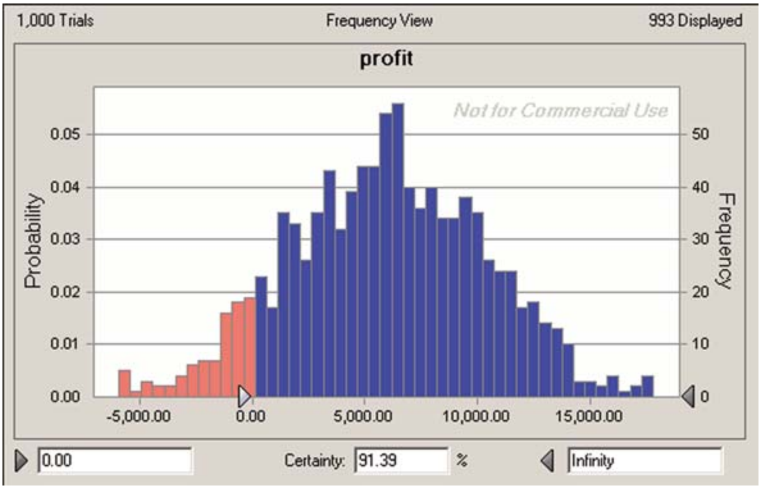
Fig. 9.7 Retailing model

costs. Holding costs at the factory were $0.25 times sum of ending inventory, at the assembler $0.40 times sum of ending inventory, at the warehouse 0.50 times ending inventory, and at the retailers $1 times sum of ending inventories. Shipping costs were $1,000 per day from factory to assembler, $700 per day from assembler to warehouse, and $300 per day from warehouse to retailer. The results of 1,000 repetitions are shown in Fig. 9.8.

Here average profit for a month is $5,942, with a minimum a loss of $8,699 and a maximum a gain of $18,922. There was a 0.0861 probability of a negative profit. The amount of shortage across the system is shown in Fig. 9.9. The average was 138.76, with a range of 33–279 over the 1,000 simulation repetitions.

The central limit theorem can be shown to have effect, as the sum of the five retailer shortfalls has a normally shaped distribution. Figure 9.10 shows shortfall at the wholesale level, which had only one entity.

The average wholesale shortages was 15.73, with a minimum of 0 and a maximum of 82. Crystal Ball output indicates a probability of shortfall of 0.9720, meaning a 0.0280 probability of going the entire month without having shortage at the wholesale level.

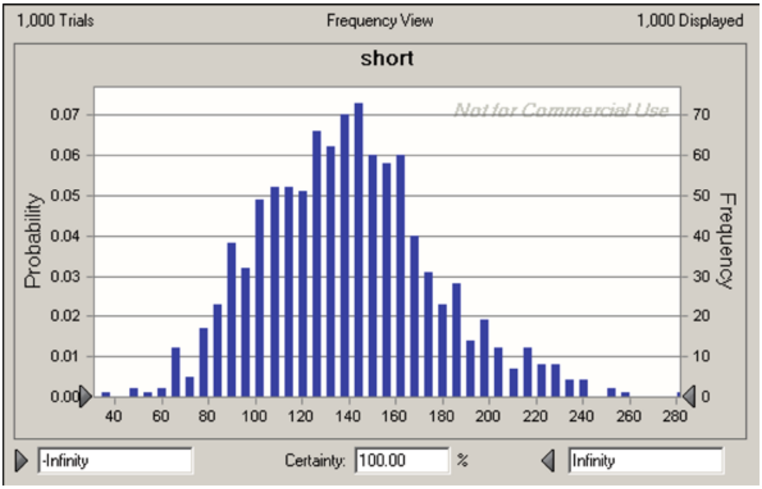


0.00 Certainty: 91.39 % Infinity

Fig. 9.8 Overall system profit for basic model

Push System

The difference in this model is that production at the factory (column C in Fig. 9.4) is a constant 20 per day, the amount sent from the factory to the assembler (column D in Fig. 9.4) is also 20 per day, the amount ordered by the wholesaler (column M in Fig. 9.6) is 20, the amount sent by the wholesaler to retailers (column P in Fig. 9.6)

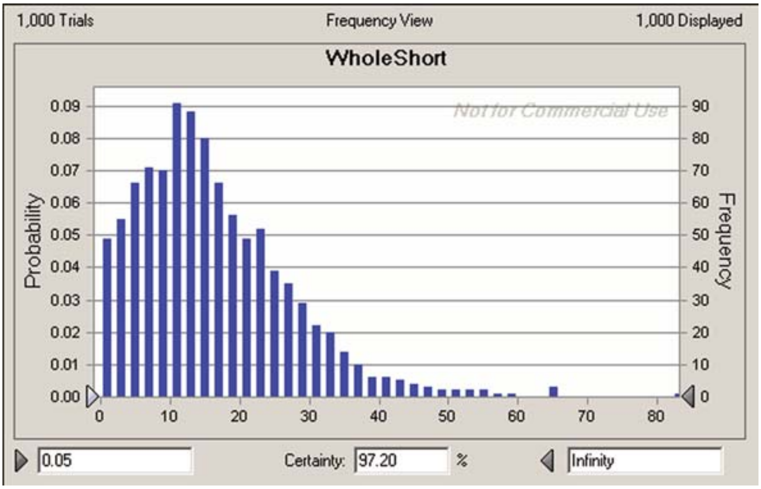


-Infinity

Certainty: 100.00 %

Infinity

Fig. 9.9 Retail shortages for basic model



0.05

Certainty: 97.20 %

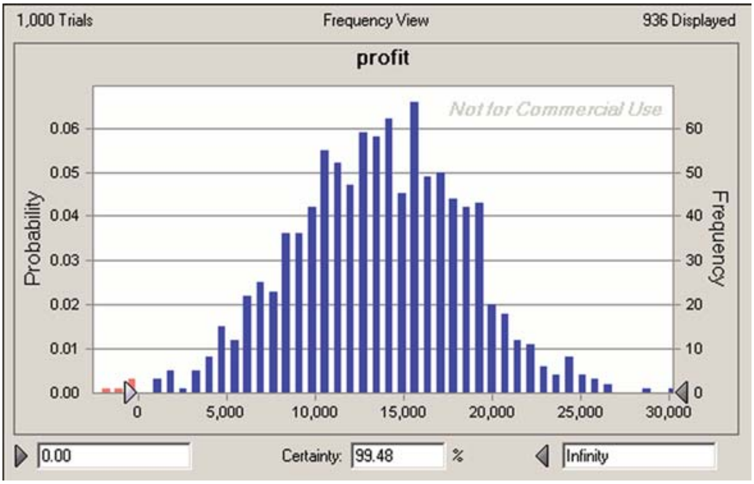
Infinity

Fig. 9.10 Wholesale shortages for basic model

is a constant 20, and the amount ordered by the wholesaler (column T in Fig. 9.7) is a constant 20.

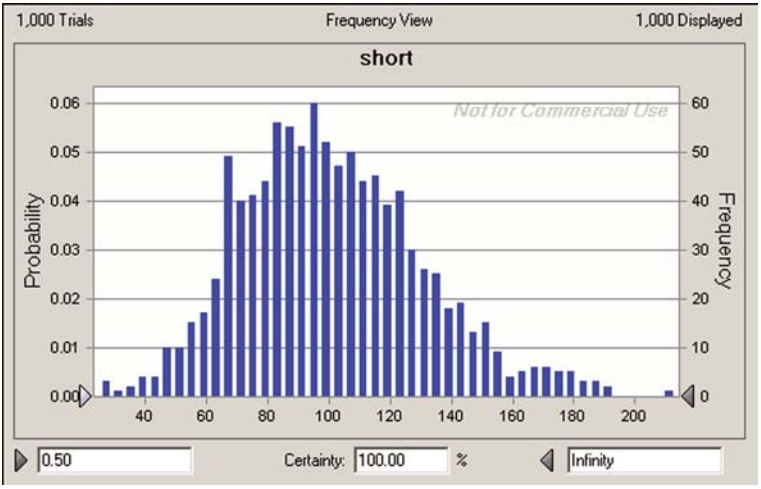
This system proved to be more profitable and safer for the given conditions. Profit is shown in Fig. 9.11.

The average profit was $13,561, almost double that of the more variable push system. Minimum profit was a loss of $2,221, with the probability of loss 0.0052. Maximum profit was $29,772. Figure 9.12 shows shortfall at the retail level.



0.00 Certainty: 99.48 % Infinity

Fig. 9.11 Push system profit

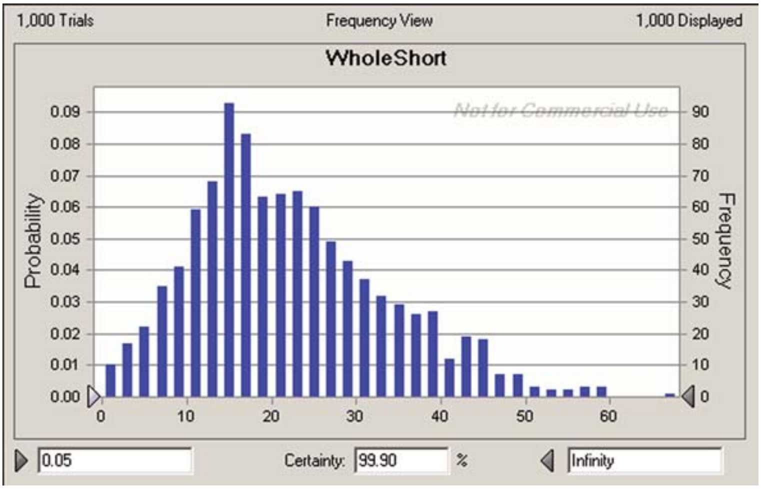


0.50 Certainty: 100.00 % Infinity

Fig. 9.12 Retail shortages for the push model

The average shortfall was only 100.32, much less than the 137.16 for the pull model. Shortfall at the wholesale level (Fig. 9.13) was an average of 21.54, ranging from 0 to 67.

For this set of assumed values, the push system performed better. But that establishes nothing, as for other conditions, and other means of coordination, a pull system could do better.



0.05 Certainty: 99.90 % Infinity

Fig. 9.13 Wholesale shortages for the push model

Monte Carlo Simulation for Analysis

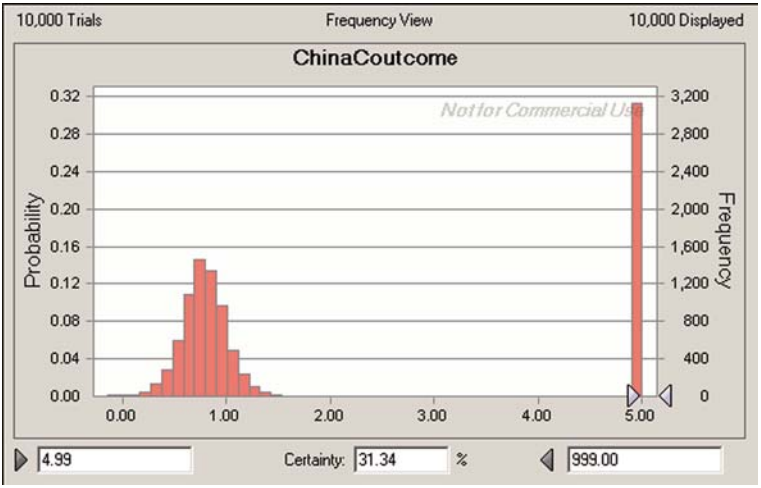
Simulation models are sets of assumptions concerning the relationship among model components. Simulations can be time-oriented (for instance, involving the number of events such as demands in a day) or process-oriented (for instance, involving queuing systems of arrivals and services). Uncertainty can be included by using probabilistic inputs for elements such as demands, inter-arrival times, or service times. These probabilistic inputs need to be described by probability distributions with specified parameters. Probability distributions can include normal distributions (with parameters for mean and variance), exponential distributions (with parameter for a mean), lognormal (parameters mean and variance), or any of a number of other distributions. A simulation run is a sample from an infinite population of possible results for a given model. After a simulation model is built, the number of trials is established. Statistical methods are used to validate simulation models and design simulation experiments.

Many financial simulation models can be accomplished on spreadsheets, such as Excel. There are a number of commercial add-on products that can be added to Excel, such as @Risk or Crystal Ball, that vastly extend the simulation power of spreadsheet models. These add-ons make it very easy to replicate simulation runs, and include the ability to correlate variables, expeditiously select from standard distributions, aggregate and display output, and other useful functions.

In supply chain outsourcing decisions, a number of factors can involve uncertainty, and simulation can be useful in gaining better understanding of systems.[11] We begin by looking at expected distributions of prices for the component to be outsourced from each location. China C in this case has the lowest estimated price, but it has a wide expected distribution of exchange rate fluctuation. These distributions will affect the actual realized price for the outsourced component. The Chinese

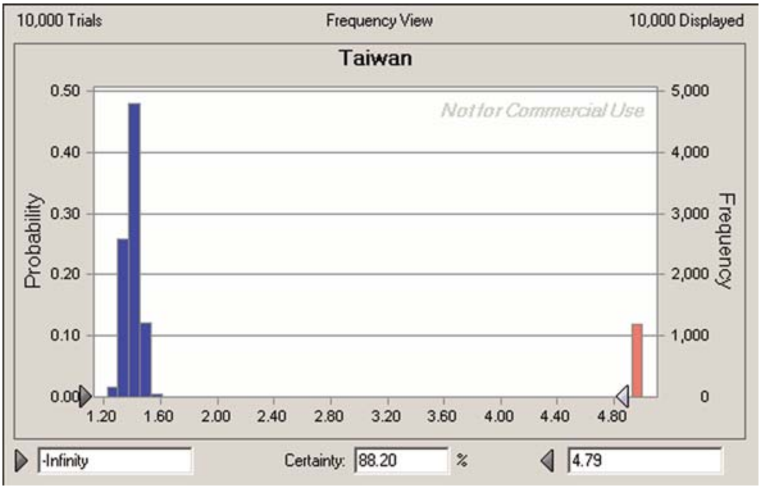
C vendor is also rated as having relatively high probabilities of failure in product compliance with contractual standards, in vendor financial survival, and in political stability of host country. The simulation is modeled to generate 1,000 samples of actual realized price after exchange rate variance, to include having to rely upon an expensive ($5 per unit) price in case of outsourcing vendor failure.

Monte Carlo simulation output is exemplified in Fig. 9.14, which shows the distribution of prices for the hypothetical Chinese outsourcing vendor C, which was the low price vendor very nearly half of the time. Figure 9.15 shows the same for the Taiwanese vendor, and Fig. 9.16 for the safer but expensive German vendor.



4.99 Certainty: 31.34 % 999.00

Fig. 9.14 Distribution of results for Chinese vendor C costs



-Infinity Certainty: 88.20 % 4.79

Fig. 9.15 Distribution of results for Taiwanese vendor costs

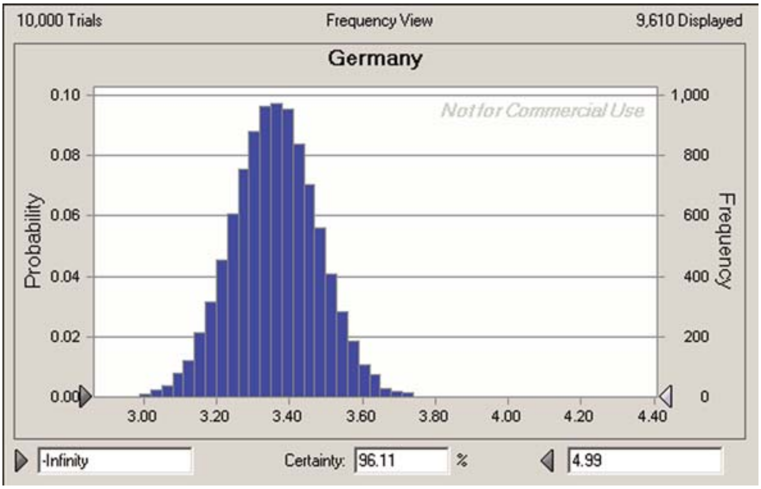


Fig. 9.16 Distribution of results for Germany vendor costs

The Chinese vendor C has a higher probability of failure (over 0.31 from all sources combined, compared to 0.30 for Indonesia). This raises its mean cost, because in case of failure, the $5 per unit default price is used. There is a cluster around the contracted cost of $0.60, with a minimum dropping slightly below 0 due to exchange rate variance, a mean of $0.78 and a maximum of $1.58 given survival in all three aspects of risk modeled. There is a spike showing a default price of $5.00 per unit in 0.3134 of the cases. Thus while the contractual price is lowest for this alternative, the average price after consideration of failure is $2.10.

Table 9.5 shows comparative output. Simulation provides a more complete picture of the uncertainties involved.

Table 9.5 Simulation output

Vendor	Mean cost	Min cost	Max cost	Probability of failure	Probability low	AvgCost if didn't fail	Average overall
China B	0.70	–0.01	1.84	0.2220	0.1370	0.91	1.82
Taiwan	1.36	1.22	1.60	0.1180	0.0033	1.41	1.83
China C	0.60	0.05	1.58	0.3134	0.4939	0.78	2.10
China A	0.82	–0.01	2.16	0.2731	0.0188	1.07	2.14
Indonesia	0.80	0.22	1.61	0.2971	0.1781	0.96	2.16
Arizona	1.80	1.80	1.80	0.2083	0.0001	2.71	2.47
Vietnam	0.85	0.40	1.49	0.3943	0.1687	0.94	2.54
Alabama	2.05	2.05	2.05	0.2472	0		2.78
Ohio	2.50	2.50	2.50	0.2867	0		3.22
Germany	3.20	2.90	3.81	0.0389	0		3.42

Note: Average overall assumes cost of $5 to supply chain should vendor fail.

Probabilities of being the low-cost alternative are also shown. The greatest probability was for China C at 0.4939, with Indonesia next at 0.1781. The expensive (but safer) alternatives of Germany and Alabama both were never low (and thus were dominated in the DEA model). But Germany had a very high probability of survival, and in the simulation could appear as the best choice (rarely).

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Chapter 10
Value at Risk

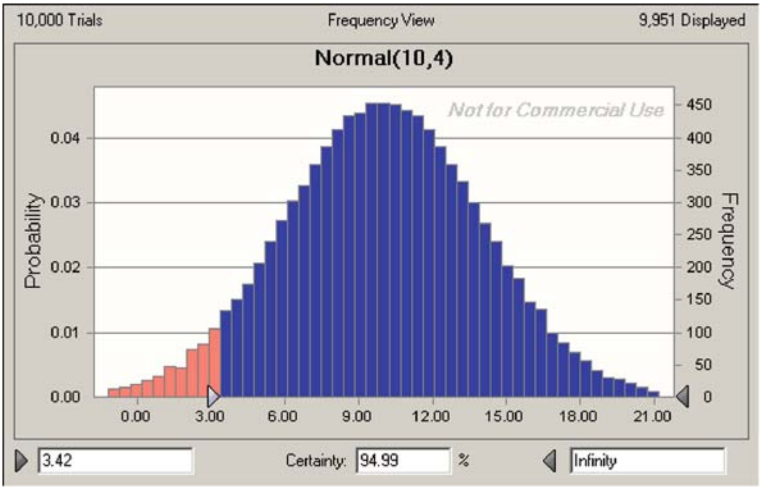
Value at risk (VaR) is one of the most widely used models in risk management. It is based on probability and statistics.[1] VaR can be characterized as a maximum expected loss, given some time horizon and within a given confidence interval. Its utility is in providing a measure of risk that illustrates the risk inherent in a portfolio with multiple risk factors, such as portfolios held by large banks, which are diversified across many risk factors and product types. VaR is used to estimate the boundaries of risk for a portfolio over a given time period, for an assumed probability distribution of market performance. The purpose is to diagnose risk exposure.

Definition

Value at risk describes the probability distribution for the value (earnings or losses) of an investment (firm, portfolio, etc.). The mean is a point estimate of a statistic, showing historical central tendency. Value at risk is also a point estimate, but offset from the mean. It requires specification of a given probability level, and then provides the point estimate of the return or better expected to occur at the prescribed probability. For instance, Fig. 10.1 gives the normal distribution for a statistic with a mean of 10 and a standard deviation of 4 (Crystal Ball was used, with 10,000 replications).

This indicates a 0.95 probability (for all practical purposes) of a return of at least 3.42. The precise calculation can be made in Excel, using the NormInv function for a probability of 0.05, a mean of 10, and a standard deviation of 4, yielding a return of 3.420585, which is practically the same as the simulation result shown in Fig. 10.1. Thus the value of the investment at the specified risk level of 0.05 is 3.42. The interpretation is that there is a 0.05 probability that things would be worse than the value at this risk level. Thus the greater the degree of assurance, the lower the value at risk return. The value at the risk level of 0.01 would only be 0.694609.

D.L. Olson, D. Wu, *Enterprise Risk Management Models*,
DOI 10.1007/978-3-642-11474-8_10,



3.42

Certainty: 94.99 %

Infinity

Fig. 10.1 Normal distribution (10, 4)

The Use of Value at Risk

VaR is globally accepted by regulatory bodies responsible for supervision of banking activities. These regulatory bodies, in broad terms, enforce regulatory practices as outlined by the Basel Committee on Banking Supervision of the Bank for International Settlements (BIS). The regulator that has responsibility for financial institutions in Canada is the Office of the Superintendent of Financial Institutions (OSFI), and OSFI typically follows practices and criteria as proposed by the Basel Committee.

A key agreement of the Basel Committee is the Basel Capital Accord (generally referred to as “Basel” or the “Basel Accord”), which has been updated several times since 1988. From the point of view of Market Risk Operations, the most significant Amendment to the Basel Accord occurred in January 1996.

In the 1996 (updated, 1998) Amendment to the Basel Accord, banks are encouraged to use internal models to measure Value at Risk, and the numbers produced by these internal models support capital charges to ensure the capital adequacy, or liquidity, of the bank. Some elements of the minimum standard established by Basel are:

- VaR should be computed daily, using a 99th percentile, one-tailed confidence interval
- A minimum price shock equivalent to ten trading days be used. This is called the “holding period” and simulates a 10-day period of liquidating assets in a period of market crisis.
- The model should incorporate a historical observation period of at least 1 year
- The capital charge is set at a minimum of three times the average of the daily value-at-risk of the preceding 60 business days

In practice, these minimum standards mean that the VaR that is produced by the Market Risk Operations area is multiplied first by the square root of 10 (to simulate 10 days holding) and then multiplied by a minimum capital multiplier of 3 to establish capital held against regulatory requirements.

In summary, VaR provides the worst expected loss at the 99% confidence level. That is, a 99% confidence interval produces a measure of loss that will be exceeded only 1% of the time. But this does mean there will likely be a larger loss than the VaR calculation two or three times in a year. This is compensated for by the inclusion of the multiplicative factors, above, and the implementation of Stress Testing, which falls outside the scope of the activities of Market Risk Operations.

Various approaches can be used to compute VaR, of which three are widely used: Historical Simulation, Variance-covariance approach, and Monte Carlo simulation. Variance-covariance approach is used for investment portfolios, but it does not usually work well for portfolios involving options that are close to delta neutral. Monte Carlo simulation solves the problem of non-linearity approximation if model error is not significant, but it suffers some technical difficulties such as how to deal with time-varying parameters and how to generate maturation values for instruments that mature before the VaR horizon. We present Historical Simulation and Variance-covariance approach in the following two sections. We will demonstrate Monte Carlo Simulation in a later section of this chapter.

Historical Simulation

Historical simulation is a good tool to estimate VAR in most banks. Observations of day-over-day changes in market conditions are captured. These market conditions are represented using upwards of 100,000 points daily of observed and implied Market Data. This historical market data is captured and used to generate historical "shocks" to current spot market data. This shocked market data is used to price the Bank's trading positions as against changing market conditions, and these revalued positions then are compared against the base case (using spot data). This simulates a theoretical profit or loss. Each day of historically observed data produces a theoretical profit/loss number in this way, and all of these theoretical P&L numbers produce a distribution of theoretical profits/losses. The (1-day) VaR can then be read as the 99th percentile of this distribution.

The primary advantage of historical simulation is ease of use and implementation. In Market Risk Operations, historical data is collected and reviewed on a regular basis, before it is added to the historical data set. Since this data corresponds to historical events, it can be reviewed in a straightforward manner. Also, the historical nature of the data allows for some clarity of explanation of VaR numbers. For instance, the Bank's VaR may be driven by widening credit spreads, or by decreasing equity volatilities, or both, and this will be visible in actual historical data. Additionally, historical data implicitly contains correlations and non-linear effects (e.g. gamma, vega and cross-effects).

The most obvious disadvantage of historical simulation is the assumption that the past presents a reasonable simulation of future events. Additionally, a large bank usually holds a large portfolio, and there can be considerable operational overhead involved in producing a VaR against a large portfolio with dependencies on a large and varied number of model inputs. All the same, other VaR methods, such as variance-covariance (VCV) and Monte Carlo simulation, produce essentially the same objections. The main alternative to historical simulation is to make assumptions about the probability distributions of the returns on the market variables and calculate the probability distribution of the change in the value of the portfolio analytically. This is known as the variance-covariance approach. VCV is a parametric approach and contains the assumption of normality, and the assumption of the stability of correlation and at the same time. Monte Carlo simulation provides another tool to these two methods. Monte Carlo methods are dependent on decisions regarding model calibration, which have effectively the same problems. No VaR methodology is without simplifying assumptions, and several different methods are in use at institutions worldwide. The literature on volatility estimation is large and seemingly subject to unending growth, especially in acronyms.[2]

Variance-Covariance Approach

VCV Models portfolio returns as a multivariate normal distribution. We can use a position vector containing cash flow present values to represent all components of the portfolio and describe the portfolio. VCV approach concerns most the return and covariance matrix (Q) representing the risk attributes of the portfolio over the chosen horizon. The standard deviation of portfolio value (σ), also called volatility, is computed:

$$\sigma = \sqrt{h^t Q h} \tag{1}$$

The volatility (σ) is then scaled to find the desired centile of portfolio value that is the predicted maximum loss for the portfolio or VaR:

$$\begin{aligned} &\text{VaR} = \sigma f(Y) \\ &\text{where:} \quad f(Y) \text{ is the scale factor for centile} Y. \end{aligned} \tag{2}$$

For example, for a multivariate normal return distribution, $f(Y) = 2.33$ for $Y = 1\%$.

It is then easy to calculate VaR from the standard deviation (1-day VaR = 2.33 s). The simplest assumption is that daily gains/losses are normally distributed and independent. The N-day VaR equals $\sqrt{N}$ times the 1-day VaR. When there is autocorrelation equal to r the multiplier is increased from N to

$$N + 2(N-1)\rho + 2(N-2)\rho^2 + 2(N-3)\rho^3 + \ldots 2\rho^{n-1}$$

Besides being easy to compute, VCV also lends itself readily to the calculation of the marginal risk (Marginal VaR), Incremental VaR and Component VaR of candidate trades. For a Portfolio where an amount x_i is invested in the ith component of the portfolio, these three VaR measures are computed as:

- Marginal VaR: $\frac{\partial \mathrm{VaR}}{\partial x_i}$
- Incremental VaR: Incremental effect of ith component on VaR
- Component VaR $x_i \frac{\partial \mathrm{VaR}}{\partial x_i}$

VCV uses delta-approximation, which means the representative cash flow vector is a linear approximation of positions. In some cases, a second-order term in the cash flow representation is included to improve this approximation.[3] However, this does not always improve the risk estimate and can only be done with the sacrifice of some of the computational efficiency. In general, VCV works well in calculating linear instruments such as forward, interest rate SWAP, but works quite badly in non-linear instruments such as various options.

Monte Carlo Simulation of VaR

Simulation models are sets of assumptions concerning the relationship among model components. Simulations can be time-oriented (for instance, involving the number of events such as demands in a day) or process-oriented (for instance, involving queuing systems of arrivals and services). Uncertainty can be included by using probabilistic inputs for elements such as demands, inter-arrival times, or service times. These probabilistic inputs need to be described by probability distributions with specified parameters. Probability distributions can include normal distributions (with parameters for mean and variance), exponential distributions (with parameter for a mean), lognormal (parameters mean and variance), or any of a number of other distributions. A simulation run is a sample from an infinite population of possible results for a given model. After a simulation model is built, a selected number of trials is established. Statistical methods are used to validate simulation models and design simulation experiments.

Many financial simulation models can be accomplished on spreadsheets, such as Excel. There are a number of commercial add-on products that can be added to Excel, such as @Risk or Crystal Ball, that vastly extend the simulation power of spreadsheet models.[4] These add-ons make it very easy to replicate simulation runs, and include the ability to correlate variables, expeditiously select from standard distributions, aggregate and display output, and other useful functions.

The Simulation Process

Using simulation effectively requires careful attention to the modeling and implementation process. The simulation process consists of five essential steps:

1. *Develop a conceptual model of the system or problem under study.* This step begins with understanding and defining the problem, identifying the goals and objectives of the study, determining the important input variables, and defining output measures. It might also include a detailed logical description of the system that is being studied. Simulation models should be made as simple as possible to focus on critical factors that make a difference in the decision. The cardinal rule of modeling is to build simple models first, then embellish and enrich them as necessary.
2. *Build the simulation model.* This includes developing appropriate formulas or equations, collecting any necessary data, determining the probability distributions of uncertain variables, and constructing a format for recording the results. This might entail designing a spreadsheet, developing a computer program, or formulating the model according to the syntax of a special computer simulation language (which we discuss further in Chap. 7).
3. *Verify and validate the model.* Verification refers to the process of ensuring that the model is free from logical errors; that is, that it does what it is intended to do. Validation ensures that it is a reasonable representation of the actual system or problem. These are important steps to lend credibility to simulation models and gain acceptance from managers and other users. These approaches are described further in the next section.
4. *Design experiments using the model.* This step entails determining the values of the controllable variables to be studied or the questions to be answered in order to address the decision maker's objectives.
5. *Perform the experiments and analyze the results.* Run the appropriate simulations to obtain the information required to make an informed decision.

As with any modeling effort, this approach is not necessarily serial. Often, you must return to pervious steps as new information arises or as results suggest modifications to the model. Therefore, simulation is an evolutionary process that must involve not only analysts and model developers, but also the users of the results.

Demonstration of VaR Simulation

We use an example Monte Carlo simulation model published by Beneda[5] to demonstrate simulation of VaR and other forms of risk. Beneda considered four risk categories, each with different characteristics of data availability:

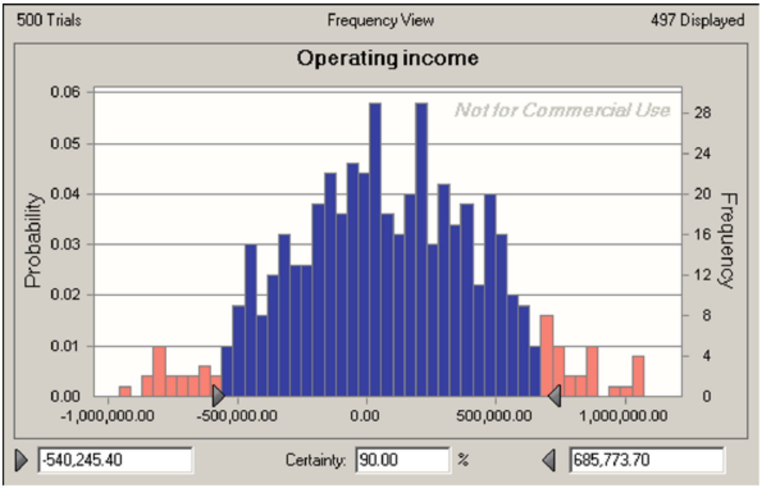
- Financial risk – controllable (interest rates, commodity prices, currency exchange)
- Pure risk – controllable (property loss and liability)
- Operational – uncontrollable (costs, input shortages)
- Strategic – uncontrollable (product obsolescence, competition)

Beneda's model involved forward sale (45 days forward) of an investment (CD) with a price that was expected to follow the uniform distribution ranging from 90 to 110. Half of these sales (20,000 units) were in Canada, which involved an exchange rate variation that was probabilistic (uniformly distributed from –0.008 to –0.004). The expected price of the CD was normally distributed with mean 0.8139, standard deviation 0.13139. Operating expenses associated with the Canadian operation were normally distributed with mean $1,925,000 and standard deviation $192,500. The other half of sales were in the US. In the US, there was risk of customer liability lawsuits (2, Poisson distribution), with expected severity per lawsuit that was lognormally distributed with mean $320,000, standard deviation $700,000. Operational risks associated with US operations were normally distributed with mean $1,275,000, standard deviation $127,500. The Excel spreadsheet model for this is given in Table 10.1.

Table 10.1 Excel model of investment

	A	B	C
1	Financial risk	Formulas	Distribution
2	Expected basis	–0.006	Uniform (–0.008, –0.004)
3	Expected price per CD	0.8139	Normal (0.8139, 0.13139)
4	March futures price	0.8149	
5	Expected basis 45 days	=B2	
6	Expected CD futures	0.8125	
7	Operating expenses	1.925	Normal (1,925,000, 192,500)
8	Sales	20,000	
9			
10	Price $US	100	Uniform (90, 110)
11	Sales	20,000	
12	Current	0.8121	
13	Receipts	=B10*B11/B12	
14	Expected exchange rate	=B3	
15	Revenues	=B13*B14	
16	COGS	=B7*1000000	
17	Operating income	=B15–B16	
18			
19	Local sales	20,000	
20	Local revenues	=B10*B19	
21	Lawsuit frequency	2	Poisson (2)
22	Lawsuit severity	320,000	Lognormal (320,000, 700,000)
23	Operational risk	1,275,000	Normal (1,275,000, 127,500)
24	Losses	=B21*B22+B23	
25	Local income	=B20–B24	
26			
27	Total income	=B17+B25	
28	Taxes	=0.35*B27	
29	After tax income	=B27–B28	

In Crystal Ball, entries in cells B2, B3, B7, B10, B21, B22 and B23 were entered as assumptions with the parameters given in column C. Prediction cells were defined for cells B17 (Canadian net income) and B29 (Total net income after tax). Results for cell B17 are given in Fig. 10.2, with a probability of 0.9 prescribed in Crystal Ball so that we can identify the VaR at the 0.05 level.



-540,245.40

Certainty: 90.00 %

685,773.70

Fig. 10.2 Output for Canadian investment

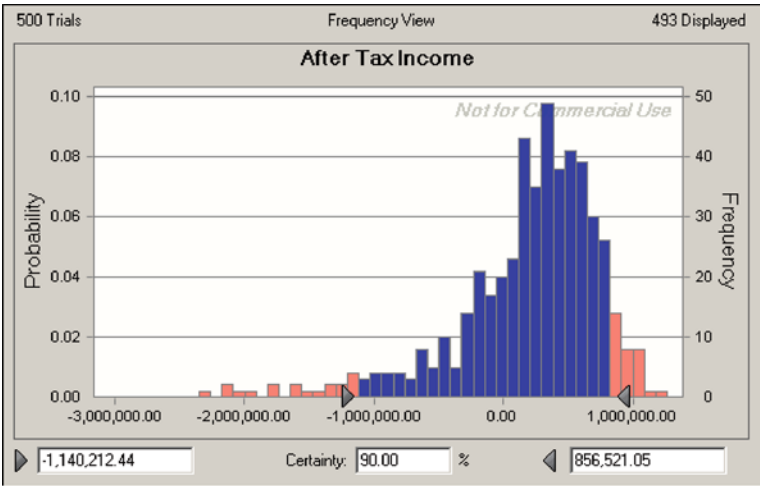
Statistics are given in Table 10.2.

Table 10.2 Operating income forecast

Statistic	Forecast values
Trials	500
Mean	78,413.99
Median	67,861.89
Mode	–
Standard deviation	385,962.44
Variance	148,967,005,823.21
Skewness	–0.0627
Kurtosis	2.99
Coeff. of variability	4.92
Minimum	–1,183,572.09
Maximum	1,286,217.07
Mean Std. error	17,260.77

The value at risk at the 0.95 level for this investment was –540,245.40, meaning that there was a 0.05 probability of doing worse than losing $540,245.50 in US dollars. The overall investment outcome is shown in Fig. 10.3.

Statistics are given in Table 10.3.



-1,140,212.44 Certainty: 90.00 % 856,521.05

Fig. 10.3 Output for after tax income

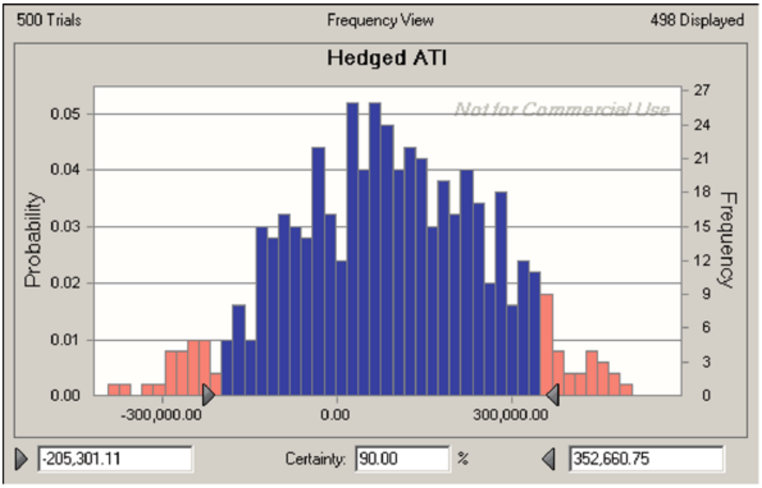
Table 10.3 After tax income forecast

Statistic	Forecast values
Trials	500
Mean	96,022.98
Median	304,091.58
Mode	–
Standard deviation	1,124,864.11
Variance	1,265,319,275,756.19
Skewness	–7.92
Kurtosis	90.69
Coeff. of variability	11.71
Minimum	–14,706,919.79
Maximum	1,265,421.71
Mean Std. error	50,305.45

On average, the investment paid off, with a positive value of $96,022.98. However, the worst case of 500 was a loss of over $14 million. (The best was a gain of over $1.265 million.) The value at risk shows a loss of $1.14 million, and Fig. 10.3 shows that the distribution of this result is highly skewed (note the skewness measures for Figs. 10.2 and 10.3).

Beneda proposed a model reflecting hedging with futures contracts, and insurance for customer liability lawsuits. Using the hedged price in cell B4, and insurance against customer suits of $640,000, the after-tax profit is shown in Fig. 10.4.

Mean profit dropped to $84,656 (standard deviation $170,720), with minimum –$393,977 (maximum gain $582,837). The value at risk at the 0.05 level was a



-205,301.11 Certainty: 90.00 % 352,660.75

Fig. 10.4 After-tax profit with hedging and insurance

loss of $205,301. Thus there was an expected cost of hedging (mean profit dropped from $96,022 to $84,656), but the worst case was much improved (loss of over $14 million to loss of $393,977) and value at risk improved from a loss of over $1.14 million to a loss of $205,000.

Conclusions

Value at risk is a useful concept in terms of assessing probabilities of investment alternatives. It is a point estimator, like the mean (which could be viewed as the value at risk for a probability of 0.5). It is only as valid as the assumptions made, which include the distributions used in the model and the parameter estimates. This is true of any simulation. However, value at risk provides a useful tool for financial investment. Monte Carlo simulation provides a flexible mechanism to measure it, for any given assumption.

However, value at risk has undesirable properties, especially for gain and loss data with non-elliptical distributions. It satisfies the well-accepted principle of diversification under assumption of normally distributed data. However, it violates the widely accepted subadditive rule; i.e., the portfolio VaR is not smaller than the sum of component VaR. The reason is that VaR only considers the extreme percentile of a gain/loss distribution without considering the magnitude of the loss. As a consequence, a variant of VaR, usually labeled *Conditional-Value-at-Risk*(or CVaR), has been used. With respect to computational issues, optimization CVaR can be very simple, which is another reason for adoption of CVaR. This pioneer work was initiated by Rockafellar and Uryasev,[6] where CVaR constraints in optimization problems can be formulated as linear constraints. CVaR represents a weighted average between the value at risk and losses exceeding the value at risk. CVaR is a risk assessment approach used to reduce the probability a portfolio will incur large losses assuming a specified confidence level. We will show how specified confidence levels can be modeled through chance constraints in the next chapter. It is possible to maximize portfolio return subject to constraints including Conditional Value-at-Risk (CVaR) and other downside risk measures, both absolute and relative to a benchmark (market and liability-based). Simulation CVaR based optimization models can also be developed.

Notes

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Chapter 11
Chance Constrained Programming

Chance constrained programming was developed as a means of describing constraints in mathematical programming models in the form of probability levels of attainment.[1] Consideration of chance constraints allows decision makers to consider mathematical programming objectives in terms of the probability of their attainment. If α is a predetermined confidence level desired by a decision maker, the implication is that a constraint will be violated at most $(1–\alpha)$ of all possible cases.

Chance constraints are thus special types of constraints in mathematical programming models, where there is some objective to be optimized subject to constraints. A typical mathematical programming formulation might be:

$$\begin{aligned}&\text{Maximize}\, f(X)\\&\text{Subject to:}\, Ax \le b\end{aligned}$$

The objective function $f(X)$ can be profit, with the function consisting of n variables X as the quantities of products produced and $f(X)$ including profit contribution rate constants. There can be any number m of constraints in Ax, each limited by some constant b. Chance constraints can be included in Ax, leading to a number of possible chance constraint model forms. Charnes and Cooper presented three formulations[2]:

(1) Maximize the expected value of a probabilistic function
    Maximize E[Y] (where $Y = f(X)$)
    Subject to: $\Pr\{Ax \le b\} \ge \alpha$

Any coefficient of this model (Y, A, b) may be probabilistic. The intent of this formulation would be to maximize (or minimize) a function while assuring α probability that a constraint is met. While the expected value of a function usually involves a linear functional form, chance constraints will usually be nonlinear. This formulation would be appropriate for many problems seeking maximum profit subject to staying within resource constraints at some specified probability.

D.L. Olson, D. Wu, *Enterprise Risk Management Models*,
DOI 10.1007/978-3-642-11474-8_11,

(2) Minimize variance
Min Var [Y]
Subject to: $\Pr\{Ax \leq b\} \geq \alpha$

The intent is to accomplish some functional performance level while satisfying the chance constraint set. This formulation might be used in identifying portfolio investments with minimum variance, which often is used as a measure of risk.

(3) Maximize probability of satisfying a chance constraint set
Max $\Pr\{Y \geq \text{target}\}$
Subject to: $\Pr\{Ax \leq b\} \geq \alpha$

This formulation is generally much more difficult to accomplish, especially in the presence of joint chance constraints (where simultaneous satisfaction of chance constraints is required). The only practical means to do this is running a series of models seeking the highest α level yielding a feasible solution.

All three models include a common general chance constraint set, allowing probabilistic attainment of functional levels:

$$\Pr\{Ax \leq b\} \geq \alpha$$

This set is nonlinear, requiring nonlinear programming solution. This inhibits the size of the model to be analyzed, as large values of model parameters m (number of constraints) and especially n (number of variables) make it much harder to obtain a solution.

Most chance constrained applications assume normal distributions for model coefficients. Goicoechea and Duckstein presented deterministic equivalents for non-normal distributions.[3] However, in general, chance constrained models become much more difficult to solve if the variance of parameter estimates increases (the feasible region shrinks drastically when more dispersed distributions are used). The same is true if α is set at too high a value (for the same reason – the feasible region shrinks).

Chance constrained applications also usually assume coefficient independence. This is often appropriate. However, it is not appropriate in many investment analyses. Covariance elements of coefficient estimates can be incorporated within chance constraints, eliminating the need to assume coefficient independence. However, this requires significantly more data, and vastly complicates model data entry.

Chance Constrained Applications

Chance constrained models are not nearly as widespread as linear programming models. Yet there are many reported applications. A number of these involve financial planning, to include a capital rationing project mix model with random variables in cash flow and budget limits,[4] retirement fund planning models,[5] and a portfolio selection model considering multiple objectives (rate of return, liquidity, risk) subject to chance constraints involving the Tunisian stock exchange market.[6]

Beyond financial planning, chance constrained models have been applied to iron ore and coal mining planning of processing and refining, a blending application.[7] Other applications include a mixed-integer chance constrained model for production/inventory lot-sizing subject to satisfying specified service levels.[8] Chance constrained models have been used to model agent recruitment planning for call centers, again seeking an optimal solution subject to a desired service level.[9] Chance constrained models for construction planning subject to probabilistic funding have been presented,[10] as has a joint chance constrained model involving air-quality management of airborne particulate emissions control[11] and a multiattribute model for selection of infrastructure projects in an aerospace firm seeking to maximize company performance subject to probabilistic budget constraints.[12] There are green chance constrained models seeking efficient climate policies considering available investment streams and renewable energy technologies.[13]

A number of applications have appeared in the electric power industry, to include a model for scheduling power-generating units considering probabilistic demands,[14] and to determine reserve capacity.[15] Chance constraints have been used to model uncertainties such as water inflows, electricity prices, and other functions[16] and to consider hedging against supply shortage subject to financial and physical asset constraints.[17] Chance constrained models have also been applied for planning control of power system voltage distortion.[18]

Chance constraints have been incorporated into data envelopment analysis models.[19] Chance constrained programming has been compared with data envelopment analysis and multi-objective programming in a supply chain vendor selection model.[20]

Portfolio Selection

Assume a given sum of money to be invested in n possible securities. We denote by $x = (x_1, \ldots, x_n)$ is an investment proportion vector (also called a portfolio). As for the number of securities n, many large institutions have "approved lists" where n is anywhere from several hundred to a thousand. When attempting to form a portfolio to mimic a large broad based index (like S&P500, EAFE, Wilshire 5000), n can be up to several thousand. Denote by

r_i the percent return of i-th security; Other objectives to characterize the i-th security could be

- s_i is social responsibility of i-th security
- g_i is growth in sales of i-th security
- a_i is amount invested in R&D of i-th security
- d_i is dividends of i-th security
- q_i is liquidity of i-th security

Consideration of such investment objectives will lead to utilization of multi-objective programming models. The investor tries to select several possible securities from the n securities to maximize his profit, which leads to the investor's decision problem as:

$$\begin{aligned} &\text{Max } r_{\mathrm{p}} - \sum\nolimits_{i=1}^{n} r_i x_i \\ &\text{s.t.} Ax \leq b \end{aligned} \tag{1}$$

where

- r_{p} is percent return on a portfolio over the holding period.
- $Ax \leq b$, the feasible region in decision space

In the investor's decision problem (1), the quantity r_{p} to be maximized is a random variable because r_{p} is a function of the individual-security r_i random variables. Therefore, (1) is a *stochastic programming problem*. Stochastic programming models are similar to deterministic optimization problems where the parameters are known only within certain bounds but take advantage of the fact that probability distributions governing the data are known or can be estimated. To solve a stochastic programming problem, we need convert the stochastic programming to an equivalent *deterministic programming problem*. A popular way of doing this is to use utility function $U(\cdot)]$, which maps stochastic terms into their deterministic equivalents. For example, by use of the means μ_i, variances σ_{ii} and covariances σ_{ij} of the r_i, a portfolio selection problem is to maximize expected utility (Markowitz 1959)[21]

$$E[U(r_{\mathrm{p}})] = E[r_{\mathrm{p}}] - \lambda \mathrm{Var}[r_{\mathrm{p}}],$$

where $\lambda \geq 0$ a risk reversion coefficient and may be different from different investors.

In other words, a portfolio selection problem can be modeled by a trade-off between the mean and variance of random variable r_{p}:

$$\begin{aligned} &\text{Max } E[U(r_{\mathrm{p}})] = E[r_{\mathrm{p}}] - \lambda \mathrm{Var}[r_{\mathrm{p}}] \\ &\lambda \geq 0 \\ &Ax \leq b \end{aligned}$$

Assuming $[U(r_{\mathrm{p}})]$ is Taylor series expandable, the validity of $E[U(r_{\mathrm{p}})]$ and thus the above problem can be guaranteed if $[U(r_{\mathrm{p}})]$ Taylor series expandable of $\mathbf{r} = (r_1, \ldots, r_n)$ follows the multinormal distribution (Markowitz 1956). Another alternative to Markowitz's mean variance framework, chance constrained programming was employed to model the portfolio selection problem (Roy 1952). We will demonstrate the utilization of chance constrained programming to model the portfolio selection problem in the next section.

Demonstration of Chance Constrained Programming

The following example was taken from Lee and Olson (2006).[22] The Hal Chase Investment Planning Agency is in business to help investors optimize their return from investment, to include consideration of risk. Through the use of nonlinear programming models, Hal Chase can control risk.

Hal deals with three investment mediums: a stock fund, a bond fund, and his own Sports and Casino Investment Plan (SCIP). The stock fund is a mutual fund investing in openly traded stocks. The bond fund focuses on the bond market, which has a much stabler return, although significantly lower expected return. SCIP is a high-risk scheme, often resulting in heavy losses, but occasionally coming through with spectacular gains. In fact, Hal takes a strong interest in SCIP, personally studying investment opportunities and placing investments daily. The return on these mediums, as well as their variance and correlation, are given in Table 11.1.

Table 11.1 Hal Chase investment data

	Stock **S**	Bond **B**	SCIP **G**
Average return	0.148	0.060	0.152
Variance	0.014697	0.000155	0.160791
Covariance with **S**		0.000468	–0.002222
Covariance with **B**			–0.000227

Note that there is a predictable relationship between the relative performance of the investment opportunities, so the covariance terms report the tendency of investments to do better or worse given that another investment did better or worse. This indicates that variables **S** and **B** tend to go up and down together (although with a fairly weak relationship), while variable **G** tends to move opposite to the other two investment opportunities.

Hal can develop a mathematical programming model to reflect an investor's desire to avoid risk. Hal assumes that return on investments are normally distributed around the average returns reported above. He bases this on painstaking research he has done with these three investment opportunities.

Maximize Expected Value of Probabilistic Function

Using this form, the objective is to maximize return:

$$\text{Expected return} = 0.148\mathbf{S} + 0.060\mathbf{B} + 0.152\mathbf{G}$$

subject to staying within budget:

$$\text{Budget} = 1\mathbf{S} + 1\mathbf{B} + 1\mathbf{G} \leq 1{,}000$$

having a probability of positive return greater than a specified probability:

$$\Pr\{\text{Expected return} \geq 0\} \geq \alpha$$

with all variables greater than or equal to 0:

$$\mathbf{S}, \mathbf{B}, \mathbf{G} \geq 0$$

The solution will depend on the confidence limit α. Using EXCEL, and varying α from 0.5, 0.8, 0.9 and 0.95, we obtain the solutions given in Table 11.2.

Table 11.2 Results for chance constrained formulation (1)

Probability {return ≥0}	α	Stock	Bond	Gamble	Expected return
0.50	0	–	–	1,000.00	152.00
0.80	0.253	379.91	–	620.09	150.48
0.90	0.842	556.75	–	443.25	149.77
0.95	1.282	622.18	–	377.82	149.51
0.99	2.054	668.92	–	331.08	149.32

The probability determines the penalty function α. At a probability of 0.80, the one-tailed normal z-function is 0.253, and thus the chance constrained is:

$$0.148\mathbf{S} + 0.060\mathbf{B} + 0.152\mathbf{G} - 0.253^{*}\mathrm{SQRT}(0.014697\mathbf{S}^2 + 0.000936\mathbf{SB} \\ -0.004444\mathbf{SG} + 0.000155\mathbf{B}^2 - 0.000454\mathbf{BG} + 0.160791\mathbf{G}^2)$$

The only difference in the constraint set for the different rows of Table 11.2 is that α is varied. The affect is seen is that investment is shifted from the high risk gamble to a bit safer stock. The stock return has low enough variance to assure the specified probabilities given. Had it been higher, the even safer bond would have entered into the solution at higher specified probability levels.

Minimize Variance

With this chance constrained form, Hal is risk averse. He wants to minimize risk subject to attaining a prescribed level of gain. The variance-covariance matrix measures risk in one form, and Hal wants to minimize this function.

$$\text{Min } 0.014697\mathbf{S}^2 + 0.000936\mathbf{SB} - 0.004444\mathbf{SG} + 0.000155\mathbf{B}^2 - 0.000454\mathbf{BG} \\ + 0.160791\mathbf{G}^2$$

This function can be constrained to reflect other restrictions on the decision. For instance, there typically is some budget of available capital to invest.

$$\mathbf{S} + \mathbf{B} + \mathbf{G} \leq 1{,}000$$

for a \$1,000 budget

Finally, Hal only wants to minimize variance given that he attains a prescribed expected return. Hal wants to explore four expected return levels: \$50/\$1,000 invested, \$100/\$1,000 invested, \$150/\$1,000 invested, and \$200/\$1,000 invested. Note that these four levels reflect expected returns of 5, 10, 15, and 20%.

$$0.148\mathbf{S} + 0.06\mathbf{B} + 0.152\mathbf{G} \geq r$$

where $r = 50$, 100, 150, and 200

Solution Procedure

The EXCEL input file will start off with the objective, MIN followed by the list of variables. Then we include the constraint set. The constraints can be stated as you want, but the partial derivatives of the variables need to consider each constraint stated in less-than-or-equal-to form. Therefore, the original model is transformed to:

$$\begin{aligned}
&\text{Min } 0.014697\mathbf{S}^2 + 0.000936\mathbf{SB} - 0.004444\mathbf{SG} + 0.000155\mathbf{B}^2 - 0.000454\mathbf{BG} \\
&\qquad + 0.160791\mathbf{G}^2 \\
&\text{s.t. } \mathbf{S} + \mathbf{B} + \mathbf{G} \leq 1{,}000 && \text{budget constraint} \\
&\quad 0.148\mathbf{S} + 0.06\mathbf{B} + 0.152\mathbf{G} \geq 50 && \text{gain constraint} \\
&\quad \mathbf{S}, \mathbf{B}, \mathbf{G} \geq 0
\end{aligned}$$

The solution for each of the four gain levels are given in Table 11.3.

Table 11.3 Results for chance constrained formulation (2)

Specified gain	Variance	Stock	Bond	Gamble
≥50	106.00	–	825.30	3.17
≥100	2,928.51	406.31	547.55	46.14
≥150	42,761	500.00	–	500.00
≥152	160,791	–	–	1,000.00

The first solution indicates that the lowest variance with an expected return of \$50 per \$1,000 invested would be to invest \$825.30 in **B** (the bond fund), \$3.17 in **G** (the risky alternative), and keeping the 171.53 slack. The variance is \$106.002. This will yield an average return of 5% on the money invested. Increasing specified gain to \$100 yields the designed expected return of \$100 with a variance of \$2,928.51. Raising expected gain to 150 yields the prescribed \$150 with a variance of \$42,761.06. Clearly this is a high risk solution. But it also is near the maximum expected return (if all $1,000 was placed on the riskiest alternative, **G**, the expected return would be maximized at $152 per $1,000 invested). A model specifying a gain of $200 yields an infeasible solution, and thus by running multiple models, we can identify the maximum gain available (matching the linear programming model without chance constraints). It can easily be seen that lower variance is obtained by investing in bonds, then shifting to stocks, and finally to the high-risk gamble option.

Maximize Probability of Satisfying Chance Constraint

The third chance constrained form is implicitly attained by using the first form example above, stepping up α until the model becomes infeasible. When the probability of satisfying the chance constraint was set too high, a null solution was generated (don't invest anything – keep all the $1,000). Table 11.4 shows solutions obtained, with the highest α yielding a solution being 4.8, associated with a probability very close to 1.0 (0.999999 according to EXCEL).

Table 11.4 Results for chance constrained formulation (3)

α	Stock	Bond	Gamble	Expected return
3	157.84	821.59	20.57	75.78
4	73.21	914.93	11.86	67.53
4.5	406.31	547.55	46.14	64.17
4.8	500.00	–	500.00	61.48
4.9 and up	–	–	–	0

Real Stock Data

To check the validity of the ideas presented, we took real stock data from the Internet, taking daily stock prices for six dispersed, large firms, as well as the S&P500 index. Data was manipulated to obtain daily rates of return over the period 1999 through 2008 (2,639 observations – dividing closing price by closing price of prior day).

$$r = \frac{V_t}{V_{t-1}}$$

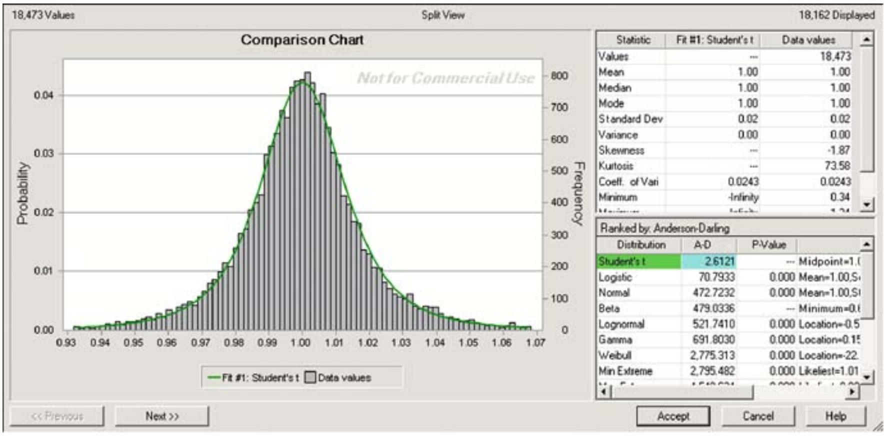
where V_t = return for day t and V_{t-1} = return for the prior day. (The arithmetic return yields identical results, only subtracting 1 from each data point.)

$$r_{arith} = \frac{V_t - V_{t-1}}{V_{t-1}}$$

We first looked at possible distributions. Figure 11.1 shows the Crystal Ball best fit for all data (using the Chi-square criterion – same result for Kolmogorov-Smirnov or Anderson criteria), while Fig. 11.2 shows fit with the logistic distribution, and Fig. 11.3 with the normal distribution.

The parameters for the student-*t* distribution fit was a scale of 0.01, and 2.841 degrees of freedom. For the logistic distribution, the scale parameter was 0.01.

The data had a slight negative skew, with a skewness score of –1.87. It had a high degree of kurtosis (73.65), and thus much more peaked than a normal distribution. This demonstrates "fat tail" distributions that are often associated with financial returns. Figures 11.1 through 113.3 clearly show how the normal assumption is too spread out for probabilities close to 0.5, and too narrow for the extremes (tails). The logistic distribution gives a better fit, but student-*t* distribution does better yet.

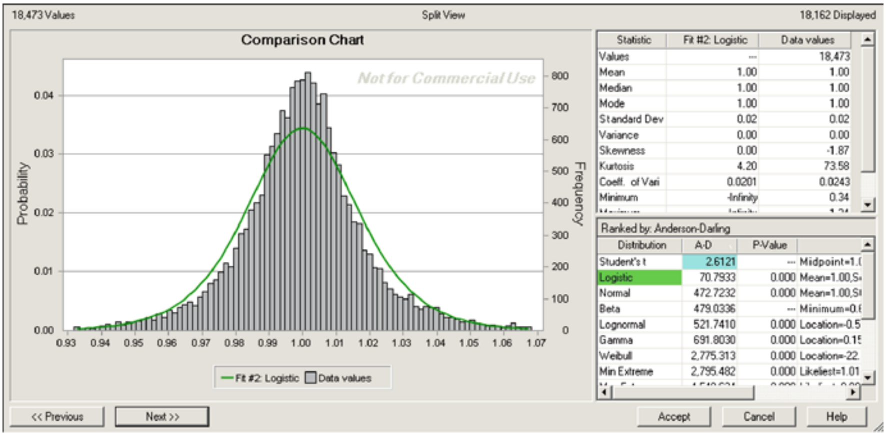


Statistic	Fit #1: Student's t	Data values
Values	---	18,473
Mean	1.00	1.00
Median	1.00	1.00
Mode	1.00	1.00
Standard Dev	0.02	0.02
Variance	0.00	0.00
Skewness	---	-1.87
Kurtosis	---	73.58
Coeff. of Vari	0.0243	0.0243
Minimum	-Infinity	0.34

Ranked by: Anderson-Darling

Distribution	A-D	P-Value	
Student's t	2.6121	---	Midpoint=1.(
Logistic	70.7933	0.000	Mean=1.00,S
Normal	472.7232	0.000	Mean=1.00,S
Beta	479.0336	---	Minimum=0.
Lognormal	521.7410	0.000	Location=-0.5
Gamma	691.8030	0.000	Location=0.1
Weibull	2,775.313	0.000	Location=-22.
Min Extreme	2,795.482	0.000	Likeliest=1.01

Fig. 11.1 Data distribution fit student-*t*

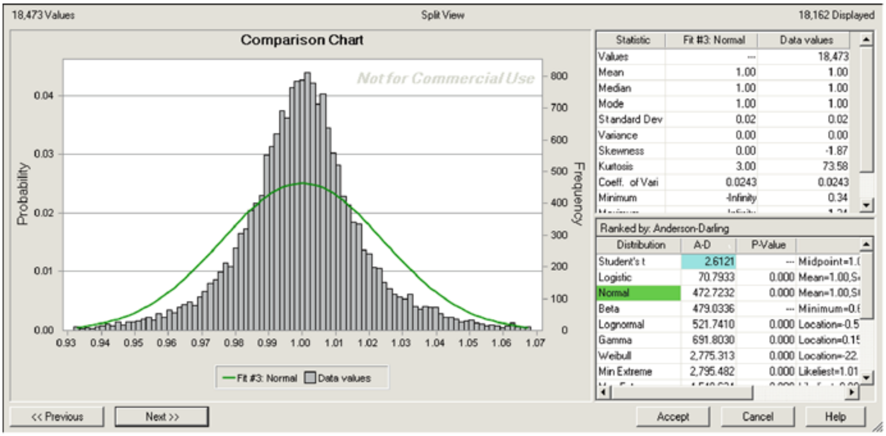


Statistic	Fit #2: Logistic	Data values
Values	---	18,473
Mean	1.00	1.00
Median	1.00	1.00
Mode	1.00	1.00
Standard Dev	0.02	0.02
Variance	0.00	0.00
Skewness	0.00	-1.87
Kurtosis	4.20	73.58
Coeff. of Vari	0.0201	0.0243
Minimum	-Infinity	0.34

Ranked by: Anderson-Darling

Distribution	A-D	P-Value	
Student's t	2.6121	---	Midpoint=1.(
Logistic	70.7933	0.000	Mean=1.00,S
Normal	472.7232	0.000	Mean=1.00,S
Beta	479.0336	---	Minimum=0.
Lognormal	521.7410	0.000	Location=-0.5
Gamma	691.8030	0.000	Location=0.1
Weibull	2,775.313	0.000	Location=-22.
Min Extreme	2,795.482	0.000	Likeliest=1.01

Fig. 11.2 Logistic fit



Statistic	Fit #3: Normal	Data values
Values	---	18,473
Mean	1.00	1.00
Median	1.00	1.00
Mode	1.00	1.00
Standard Dev	0.02	0.02
Variance	0.00	0.00
Skewness	0.00	-1.87
Kurtosis	3.00	73.58
Coeff. of Vari	0.0243	0.0243
Minimum	-Infinity	0.34

Ranked by: Anderson-Darling

Distribution	A-D	P-Value	
Student's t	2.6121	---	Midpoint=1.(
Logistic	70.7933	0.000	Mean=1.00,S
Normal	472.7232	0.000	Mean=1.00,S
Beta	479.0336	---	Minimum=0.(
Lognormal	521.7410	0.000	Location=-0.5
Gamma	691.8030	0.000	Location=0.1
Weibull	2,775.313	0.000	Location=-22.
Min Extreme	2,795.482	0.000	Likeliest=1.01

Fig. 11.3 Normal model fit to data

Table 11.5 shows means standard deviations, and covariances of these investments.

An alternative statistic for returns is the logarithmic return, or continuously compounded return, using the formula:

$$r_{log} = \ln\left(\frac{V_f}{V_i}\right)$$

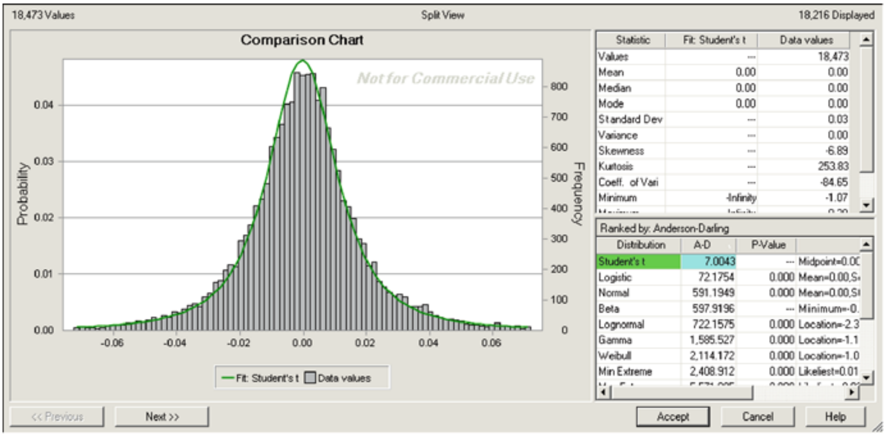
The student's *t* distribution again had the best fit, followed by logistic and normal (Fig. 11.4).

This data yields slightly different data, as shown in Table 11.6.

Like the arithmetic return, the logarithmic return is centered on 0. There is a difference (slight) between logarithmic return covariances and arithmetic return covariances. The best distribution fit was obtained with the original data (identical

Table 11.5 Daily data

	Ford	IBM	Pfizer	SAP	WalMart	XOM	S&P
Mean	1.00084	1.00033	0.99935	0.99993	1.00021	1.00012	0.99952
Std. dev	0.03246	0.02257	0.02326	0.03137	0.02102	0.02034	0.01391
Min	0.62822	0.49101	0.34294	0.81797	0.53203	0.51134	0.90965
Max	1.29518	1.13160	1.10172	1.33720	1.11073	1.17191	1.11580
Cov(Ford)	0.00105	0.00019	0.00014	0.00020	0.00016	0.00015	0.00022
Cov(IBM)		0.00051	0.00009	0.00016	0.00013	0.00012	0.00018
Cov(Pfizer)			0.00054	0.00011	0.00014	0.00014	0.00014
Cov(SAP)				0.00098	0.00010	0.00016	0.00016
Cov(WM)					0.00044	0.00011	0.00014
Cov(XOM)						0.00041	0.00015
Cov(S&P)							0.00019



Statistic	Fit: Student's t	Data values
Values	---	18,473
Mean	0.00	0.00
Median	0.00	0.00
Mode	0.00	0.00
Standard Dev	---	0.03
Variance	---	0.00
Skewness	---	-6.89
Kurtosis	---	253.83
Coeff. of Vari	---	-84.65
Minimum	-Infinity	-1.07

Ranked by: Anderson-Darling

Distribution	A-D	P-Value	
Student's t	7.0043	---	Midpoint=0.0
Logistic	72.1754	0.000	Mean=0.00,S
Normal	591.1949	0.000	Mean=0.00,S
Beta	597.9196	---	Minimum=-0.
Lognormal	722.1575	0.000	Location=-2.3
Gamma	1,585.527	0.000	Location=-1.1
Weibull	2,114.172	0.000	Location=-1.0
Min Extreme	2,408.912	0.000	Likeliest=0.01

Fig. 11.4 Return for logarithmic data

Table 11.6 Daily data for logarithmic return

	Ford	IBM	Pfizer	SAP	WalMart	XOM	S&P
Mean	–0.00029	0.00015	–0.00084	–0.00038	0.00006	–0.00017	–0.00068
Std. Dev	0.03278	0.02455	0.02852	0.03087	0.02254	0.02219	0.01392
Min	–0.46486	–0.71130	–1.07021	–0.20093	–0.63105	–0.67073	–0.09470
Max	0.25865	0.12364	0.09687	0.29058	0.10502	0.15863	0.10957
Cov(Ford)	0.00107	0.00019	0.00013	0.00020	0.00016	0.00015	0.00022
Cov(IBM)		0.00060	0.00009	0.00015	0.00013	0.00012	0.00018
Cov(Pfizer)			0.00081	0.00011	0.00014	0.00013	0.00014
Cov(SAP)				0.00095	0.00010	0.00016	0.00016
Cov(WM)					0.00051	0.00011	0.00014
Cov(XOM)						0.00049	0.00015
Cov(S&P)							0.00019

to arithmetic return), so we used that data for our chance constrained calculations. If logarithmic return data was preferred, the data in Table 11.6 could be used in the chance constrained formulations.

Chance Constrained Model Results

We ran the data into chance constrained models assuming a normal distribution for data, using means, variances, and covariances from Table 11.5. The model included a budget limit of \$1,000, all variables ≥ 0, chance constrained to have no loss), obtaining results shown in Table 11.7.

Maximizing return is a linear programming model, with an obvious solution of investing all available funds in the option with the greatest return (Ford). This has the greatest expected return, but also the highest variance.

Table 11.7 Model results

Model	Ford	IBM	Pfizer	SAP	WM	XOM	S&P	Return	Stdev
Max Return	1,000.000	–	–	–	–	–	–	1,000.84	32.404
Min Variance	–	45.987	90.869	30.811	127.508	116.004	588.821	999.76	13.156
Normal	398.381	283.785	–	–	222.557	95.277	–	1,000.49	18.534
Pr{>970}>0.95									
t	607.162	296.818	–	–	96.020	–	–	1,000.63	23.035
Pr{>970}>0.95									
t	581.627	301.528	–	–	116.845	–	–	1,000.61	22.475
Pr{>970}>0.95									
Pr{>980}>0.9									
t	438.405	279.287	–	–	220.254	62.054	–	1,000.51	19.320
Pr{>970}>0.95									
Pr{>980}>0.9									
Pr{>990}>0.8									
Max Pr{>1,000}	16.275	109.867	105.586	38.748	174.570	172.244	382.711	999.91	13.310

Minimizing variance is equivalent to chance constrained form (2). The solution avoided Ford (which had a high variance, and spread the investment out among the other options, but had a small loss.

A series of models using chance constrained form (1) were run. Maximizing expected return subject to investment $\leq$ 1,000 as well as adding the chance constraint Pr{return$\geq$970} was run for both normal and *t*-distributions.

$$\begin{aligned} &\text{Max expected return} \\ \text{s.t.}\quad &\text{Sum investment} \leq 1{,}000 \\ &\Pr\{\text{return} \geq 970\} \geq 0.95 \\ &\text{All investments} \geq 0 \end{aligned}$$

It can be seen in Table 11.6 that the *t*-distribution was less restrictive, resulting in more investment in the riskier Ford option, but having a slightly higher variance (standard deviation). The chance constraint was binding in both assumptions (normal and student-*t*). There was a 0.9 probability return of 979.50, and a 0.8 probability of return of 988.09 by *t*-distribution. Further chance constraint models were run assuming *t*-distribution. For the model:

$$\begin{aligned} &\text{Max expected return} \\ \text{s.t.}\quad &\text{Sum investment} \leq 1{,}000 \\ &\Pr\{\text{return} \geq 970\} \geq 0.95 \\ &\Pr\{\text{return} \geq 980\} \geq 0.9 \\ &\text{All investments} \geq 0 \end{aligned}$$

The expected return was only slightly less, with the constraint Pr{return $\geq$ 980} $\geq$ 0.9 binding. There was a 0.95 probability of return of 970.73, and a 0.8 probability of return of 988.38. A model using three chance constraints was also run:

$$\begin{aligned} &\text{Max expected return} \\ \text{s.t.}\quad &\text{Sum investment} \leq 1{,}000 \\ &\Pr\{\text{return} \geq 970\} \geq 0.95 \\ &\Pr\{\text{return} \geq 980\} \geq 0.9 \\ &\Pr\{\text{return} \geq 990\} \geq 0.8 \\ &\text{All investments} \geq 0 \end{aligned}$$

This yielded a solution where the 0.95 probability of return was 974.83, the 0.9 probability of return was 982.80, and the 0.8 probability of return was 990 (binding).

Finally, a model was run to maximizing probability of return $\geq$ 1,000 (chance constrained model type 3).

$$
\begin{aligned}
&\text{Minimize D} \\
&\text{s.t.} \quad \text{Sum investment} \leq 1{,}000 \\
&\qquad \Pr\{\text{return} \geq 970\} \geq 0.95 \\
&\qquad \Pr\{\text{return} \geq 980\} \geq 0.9 \\
&\qquad \text{D} = 1{,}000 - \Pr\{\text{return} \geq 1{,}000\} \geq 0.8 \\
&\qquad \text{All investments} \geq 0
\end{aligned}
$$

This was done by setting the deviation from an infeasible target. The solution yielded a negative expected return at a low variance, with the 0.95 probability of return 982.22, the 0.9 probability of return 987.71, and the 0.8 probability of return 992.67.

Conclusions

A number of different types of models can be built using chance constraints. The first form is to maximize the linear expected return subject to attaining specified probabilities of reaching specified targets. The second is to minimize variance. This second form is not that useful, in that the lowest variance is actually to not invest. Here we forced investment of the 1,000 capital assumed. The third form is to maximize probability of attaining some target, which in order to be useful, has to be infeasible.

Chance constrained models have been used in many applications. Here we have focused on financial planning, but there have been applications whenever statistical data is available in an optimization problem.

The models presented all were solved with EXCEL SOLVER. In full disclosure, we need to point out that chance constraints create nonlinear optimization models, which are somewhat unstable relative to linear programming models. Solutions are very sensitive to the accuracy of input data. There also are practical limits to model size. The variance-covariance matrix involves a number of parameters to enter into EXCEL functions, which grow rapidly with the number of variables. In the simple example there were three solution variables, with 6 elements to the variance-covariance matrix. In the real example, there were seven solution variables (investment options). The variance-covariance matrix thus involved 28 nonlinear expressions.

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Chapter 12
Data Envelopment Analysis in Enterprise Risk Management

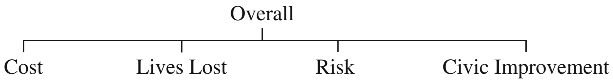
Charnes, Cooper and Rhodes[1] first introduced DEA (CCR) for efficiency analysis of Decision-making Units (DMU). DEA can be used for modeling operational processes, and its empirical orientation and absence of a priori assumptions have resulted in its use in a number of studies involving efficient frontier estimation in both nonprofit and in private sectors. DEA has become a leading approach for efficiency analysis in many fields, such as supply chain management,[2] business research and development,[3] petroleum distribution system design,[4] military logistics,[5] and government services.[6] DEA and multicriteria decision making models have been compared and extended.[7]

Moskowitz et al.[8] presented a vendor selection scenario involving nine vendors with stochastic measures given over 12 criteria. This model was used by Wu and Olson[9] in comparing DEA with multiple criteria analysis. We start with discussion of the advanced ERM technology, i.e., value-at-risk (VaR) and develop DEA VaR model as a new tool to conduct risk management in enterprises.

While risk needs to be managed, taking risks is fundamental to doing business. Profit by necessity requires accepting some risk.[10] ERM provides tools to rationally manage these risks. We will demonstrate multiple criteria and DEA models in the enterprise risk management context with a hypothetical nuclear waste repository site location problem.

Basic Data

For a set of data including a supply chain needing to select a repository for waste dump siting, we have 12 alternatives with four criteria. Criteria considered include cost, expected lives lost, risk of catastrophe, and civic improvement. Expected lives lost reflects workers as well as expected local (civilian bystander) lives lost. The hierarchy of objectives is:



D.L. Olson, D. Wu, *Enterprise Risk Management Models*,
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Table 12.1 Dump site data

Alternatives	Cost (billions)	Expected lives lost	Risk	Civic improvement
Nome AK	40	60	Very high	Low
Newark NJ	100	140	Very low	Very high
Rock Springs WY	60	40	Low	High
Duquesne PA	60	40	Medium	Medium
Gary IN	70	80	Low	Very high
Yakima Flats WA	70	80	High	Medium
Turkey TX	60	50	High	High
Wells NE	50	30	Medium	Medium
Anaheim CA	90	130	Very high	Very low
Epcot Center FL	80	120	Very low	Very low
Duckwater NV	80	70	Medium	Low
Santa Cruz CA	90	100	Very high	Very low

The alternatives available, with measures on each criterion (including two categorical measures) are given in Table 12.1.

Models require numerical data, and it is easier to keep things straight if we make higher scores be better. So we adjust the Cost and Expected Lives Lost scores by subtracting them from the maximum, and we assign consistent scores on a 0–100 scale for the qualitative ratings given Risk and Civic Improvement, yielding Table 12.2.

Table 12.2 Scores used

Alternatives	Cost	Expected lives lost	Risk	Civic improvement
Nome AK	60	80	0	25
Newark NJ	0	0	100	100
Rock Springs WY	40	100	80	80
Duquesne PA	40	100	50	50
Gary IN	30	60	80	100
Yakima flats WA	30	60	30	50
Turkey TX	40	90	30	80
Wells NE	50	110	50	50
Anaheim CA	10	10	0	0
Epcot center FL	20	20	100	0
Duckwater NV	20	70	50	25
Santa Cruz CA	10	40	0	0

Nondominated solutions can be identified by inspection. For instance, Nome AK has the lowest estimated cost, so is by definition nondominated. Similarly, Wells NE has the best expected lives lost. There is a tie for risk of catastrophe (Newark NJ and Epcot Center FL have the best ratings, with tradeoff in that Epcot Center FL has better cost and lives lost estimates while Newark NJ has better civic improvement rating, and both are nondominated). There are also is a tie for best civic improvement

(Newark NJ and Gary IN), and tradeoff in that Gary IN has better cost and lives lost estimates while Newark NJ has a better risk of catastrophe rating), and again both are nondominated. There is one other nondominated solution (Rock Springs WY), which can be compared to all of the other 11 alternatives and shown to be better on at least one alternative.

Multiple Criteria Models

Nondominance can also be established by a linear programming model. We create a variable for each criterion, with the decision variables weights (which we hold strictly greater than 0, and to sum to 1). The objective function is to maximize the sum-product of measure values multiplied by weights for each alternative site in turn, subject to this function being strictly greater than each sum-product of measure values time weights for each of the other sites. For the first alternative, the formulation of the linear programming model is:

$$\text{Max} \sum_{i=1}^{4} w_i y_1$$

s.t.

$$\sum_{i=1}^{4} w_i = 1$$

For each j from 2 to 12:

$$\sum_{i=1}^{4} w_i y x_1 \geq \sum_{i=1}^{4} w_i y_j + 0.0001$$

$$w_i \geq 0.0001$$

This model was run for each of the 12 available sites. Non-dominated alternatives (defined as at least as good on all criteria, and strictly better on at least one criterion relative to all other alternatives) are identified if this model is feasible. The reason to add the 0.0001 to some of the constraints is that strict dominance might not be identified otherwise (the model would have ties). The solution for the Newark NJ alternative was as shown in Table 12.3.

The set of weights were minimum for the criteria of Cost and Expected Lives lost, with roughly equal weights on Risk of Catastrophe and Civic Improvement. That makes sense, because Newark NJ had the best scores for Risk of Catastrophe and Civic Improvement and low scores on the other two Criteria.

Running all 12 linear programming models, six solutions were feasible, indicating that they were not dominated {Nome AK, Newark NJ, Rock Springs WY, Gary IN, Wells NE and Epcot Center FL}. The corresponding weights identified are not unique (many different weight combinations might have yielded these alternatives as feasible). These weights also reflect scale (here the range for Cost was 60, and for Lives Lost was 110, while the range for the other two criteria were 100 – in this case this difference is slight, but the scales do not need to be similar. The more dissimilar, the more warped are the weights.) For the other six dominated solutions, no set of weights would yield them as feasible. For instance, Table 12.4 shows the infeasible solution for Duquesne PA:

Here Rock Springs WY and Wells NE had higher functional values than Duquesne PA. This is clear by looking at criteria attainments. Rock Springs WY is equal to Duquesne PA on Cost and Lives Lost, and better on Risk and Civic Improvement.

Scales

The above analysis used input data with different scales. Cost ranged from 0 to 60, Lives Lost from 0 to 110, and the two subjective criteria (Risk, Civic Improvement) from 0 to 100. While they were similar, there were slightly different ranges. The resulting weights are one possible set of weights that would yield the analyzed alternative as non-dominated. If we proportioned the ranges to all be equal (divide Cost scores in Table 12.2 by 0.6, Expected Lives Lost scores by 1.1), the resulting weights would represent the implied relative importance of each criterion that would yield a non-dominated solution. The non-dominated set is the same, only weights varying. Results are given in Table 12.5.

Stochastic Mathematical Formulation

Value-at-risk (VaR) methods are popular in financial risk management.[11] VaR models were motivated in part by several major financial disasters in the late 1980s and 1990s, to include the fall of Barings Bank and the bankruptcy of Orange County. In both instances, large amounts of capital were invested in volatile markets when traders concealed their risk exposure. VaR models allow managers to quantify their risk exposure at the portfolio level, and can be used as a benchmark to compare risk positions across different markets. Value-at-risk can be defined as the expected loss

Table 12.3 MCDM LP solution for Nome AK

	Criteria	Cost	Lives	Risk	Improve	
Object	Newark NJ	0	0	100	100	99.9801
Weights		0.0001	0.0001	0.4975	0.5023	1.0000
	Nome AK	60	80	0	25	12.5708
	Rock Springs WY	40	100	80	80	79.9980
	Duquesne PA	40	100	50	50	50.0040
	Gary IN	30	60	80	100	90.0385
	Yakima flats WA	30	60	30	50	40.0485
	Turkey TX	40	90	30	80	55.1207
	Wells NE	50	110	50	50	50.0060
	Anaheim CA	10	10	0	0	0.0020
	Epcot center FL	20	20	100	0	49.7567
	Duckwater NV	20	70	50	25	37.4422
	Santa Cruz CA	10	40	0	0	0.0050

Table 12.4 LP solution for Duquesne PA

	Criteria	Cost	Lives	Risk	Improve	
Object	Duquesne PA	40	100	50	50	99.9840
Weights		0.0001	0.9997	0.0001	0.0001	1.0000
	Nome AK	60	80	0	25	79.9845
	Newark NJ	0	0	100	100	0.0200
	Rock Springs WY	**40**	**100**	**80**	**80**	**99.9900**
	Gary IN	30	60	80	100	60.0030
	Yakima Flats WA	30	60	30	50	59.9930
	Turkey TX	40	90	30	80	89.9880
	Wells NE	**50**	**110**	**50**	**50**	**109.9820**
	Anaheim CA	10	10	0	0	9.9980
	Epcot Center FL	20	20	100	0	20.0060
	Duckwater NV	20	70	50	25	69.9885
	Santa Cruz CA	10	40	0	0	39.9890

Table 12.5 Results using scaled weights

Alternative	Cost	Lives	Risk	Improve	Dominated by
Nome AK	0.9997	0.0001	0.0001	0.0001	
Newark NJ	0.0001	0.0001	0.4979	0.5019	
Rock Springs WY	0.0001	0.7673	0.0001	0.2325	
Gary IN	0.00001	0.0001	0.0001	0.9997	
Wells NE	0.0001	0.9997	0.0001	0.0001	
Epcot Center FL	0.0002	0.0001	0.9996	0.0001	
Duquesne PA					Rock Springs WY Wells NE
Yakima Flats WA					Six alternatives
Turkey TX					Rock Springs WY
Anaheim CA					All but Newark NJ
Duckwater NV					Five alternatives
Santa Cruz CA					Eight alternatives

for an investment or portfolio at a given confidence level over a stated time horizon. If we define the risk exposure of the investment as L, we can express VaR as:

$$\text{Prob}\{L \leq \text{ VaR}\} = 1 - \alpha$$

A rational investor will minimize expected losses, or the loss level at the stated probability $(1 - \alpha)$. This statement of risk exposure can also be used as a constraint in a chance-constrained programming model, imposing a restriction that the probability of loss greater than some stated value should be less than $(1 - \alpha)$.

The standard deviation or volatility of asset returns, σ, is a widely used measure of financial models such as VaR. Volatility σ represents the variation of asset returns during some time horizon in the VaR framework. This measure will be employed in our approach. Monte Carlo Simulation techniques are often applied to measure the variability of asset risk factors.[12] We will employ Monte Carlo Simulation for benchmarking our proposed method.

Stochastic models construct production frontiers that incorporate both inefficiency and stochastic error. The stochastic frontier associates extreme outliers with the stochastic error term and this has the effect of moving the frontier closer to the bulk of the producing units. As a result, the measured technical efficiency of every DMU is raised relative to the deterministic model. In some realizations, some DMUs will have a super-efficiency larger than unity.[13]

Now we consider the stochastic vendor selection model. Consider *N* suppliers to be evaluated, each has *s* random variables. Note that all input variables are transformed to output variables, as was done in Moskowitz et al.[14] The variables of supplier *j* ($j = 1,2\ldots N$) exhibit random behavior represented by $\tilde{y}_j = (\tilde{y}_{1j}, \ldots, \tilde{y}_{sj})$, where each $\tilde{y}_{rj}(r = 1,2,\ldots,s)$ has a known probability distribution. By maximizing the expected efficiency of a vendor under evaluation subject to VaR being restricted to be no worse than some limit, the following model (1) is developed:

$$\text{Max} \sum_{i=1}^{4} w_i y_1$$

$$\text{s.t.} \qquad \sum_{i=1}^{4} w_i = 1$$

$$\text{For each } j \text{ from 2 to 12:} \qquad \text{Prob}\left\{\sum_{i=1}^{4} w_i y x_1 \geq \sum_{i=1}^{4} w_i y_j + 0.0001\right\} \geq (1-\alpha)$$

$$w_i \geq 0.0001$$

Because each $\tilde{y}_j$ is potentially a random variable, it has a distribution rather than being a constant. The objective function is now an expectation, but the expectation is the mean, so this function is still linear, using the mean rather than the constant parameter. The constraints on each location's performance being greater than or equal to all other location performances is now a nonlinear function. The weights w_i are still variables to be solved for, as in the deterministic version used above.

The scalar α is referred to as the modeler's risk level, indicating the probability measure of the extent to which Pareto efficiency violation is admitted as most α proportion of the time. The $\alpha_j(0 \leq \alpha_j \leq 1)$ in the constraints are predetermined scalars which stand for an allowable risk of violating the associated constraints, where $1 - \alpha_j$ indicates the probability of attaining the requirement. The higher the value of α, the higher the modeler's risk and the lower the modeler's confidence about the 0th vendor's Pareto efficiency and vice-visa. At the $(1-\alpha)\%$ confidence level, the 0th supplier is stochastic efficient only if the optimal objective value is equal to one.

To transform the stochastic model (1) into a deterministic DEA, Charnes and Cooper[15] employed chance constrained programming.[16] The transformation steps presented in this study follow this technique and can be considered as a special case of their stochastic DEA,[17] where both stochastic inputs and outputs are used. This yields a non-linear programming problem in the variables w_i, which has computational difficulties due to the objective function and the constraints, including the variance-covariance yielding quadratic expressions in constraints. We assume that $\tilde{y}_j$ follows a normal distribution $N(\bar{y}_j, B_{jk})$, where $\bar{y}_j$ is its vector of expected value and B_{jk} indicates the variance-covariance matrix of the jth alternative with the kth alternative. The development of stochastic DEA is given in Wu and Olson (2008).[18]

We adjust the data set used in the nuclear waste siting problem by making cost a stochastic variable (following an assumed normal distribution, thus requiring a variance). The mathematical programming model decision variables are the weights on each criterion, which are not stochastic. What is stochastic is the parameter on costs. Thus the adjustment is in the constraints. For each evaluated alternative y_j compared to alternative y_k:

$$\begin{aligned}
&w_{\text{cost}}(y_{j\,\text{cost}} - z^{*}\text{SQRT}(\text{Var}[y_{j\,\text{cost}}]) + w_{\text{lives}}y_{j\,\text{lives}} + w_{\text{risk}}y_{j\,\text{risk}} + w_{\text{imp}}y_{j\ \text{imp}})\\
&\quad\geq w_{\text{cost}}(y_{k\,\text{cost}} - z\text{SQRT}(\text{Var}[y_{k\,\text{cost}}])\\
&\quad+2^{*}\text{Cov}[y_{j\,\text{cost}}, y_{k\,\text{cost}}] + \text{Var}[y_{k\ \text{cost}}]\\
&\quad+w_{\text{lives}}y_{k\,\text{lives}} + w_{\text{risk}}y_{k\,\text{imp}} + w_{\text{risk}}y_{k\,\text{imp}})
\end{aligned}$$

These functions need to include the covariance term for costs between alternative y_j compared to alternative y_k.

Table 12.6 shows the stochastic cost data in billions of dollars, and the converted cost scores (also billions of dollars transformed as \$100 billion minus the cost measure for that site) as in Table 12.2. The cost variances will remain as they were, as the relative scale did not changes.

Table 12.6 Stochastic data

Alternative	Cost measure	Mean cost	Cost variance	Expected lives lost	Risk	Civic improvement
S1 Nome AK	$N(40,6)$	60	6	80	0	25
S2 Newark NJ	$N(100,20)$	0	20	0	100	100
S3 Rock Springs WY	$N(60,5)$	40	5	100	80	80
S4 Duquesne PA	$N(60,30)$	40	30	100	50	50
S5 Gary IN	$N(70,35)$	30	35	60	80	100
S6 Yakima Flats WA	$N(70,20)$	30	20	60	30	50
S7 Turkey TX	$N(60,10)$	40	10	90	30	80
S8 Wells NE	$N(50,8)$	50	8	110	50	50
S9 Anaheim CA	$N(90,40)$	10	40	10	0	0
S10 Epcot Center FL	$N(80,50)$	20	50	20	100	0
S11 Duckwater NV	$N(80,20)$	20	20	70	50	25
S12 Santa Cruz CA	$N(90,40)$	10	40	40	0	0

The variance-covariance matrix of costs is required (Table 12.7):

The degree of risk aversion used (α) is 0.95, or a z-value of 1.645 for a one-sided distribution. The adjustment affected the model by lowering the cost parameter proportional to its variance for the evaluated alternative, and inflating it for the other alternatives. Thus the stochastic model required a 0.95 assurance that the cost for

Table 12.7 Site covariances

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12
S1	6	2	4	2	2	3	3	3	2	1	3	2
S2		20	3	10	9	5	2	1	4	5	1	4
S3			5	2	1	2	3	3	2	1	3	2
S4				30	10	8	2	2	6	5	1	4
S5					35	9	3	2	5	6	1	4
S6						20	3	2	10	8	2	12
S7							10	3	2	1	3	2
S8								8	2	1	3	2
S9									40	5	1	12
S10										50	2	8
S11											20	2
S12												40

the evaluated alternative be superior to each of the other 11 alternatives, a more difficult standard. The DEA models were run for each of the 12 alternatives. Only two of the six alternatives found to be nondominated with deterministic data above were still nondominated {Rock Springs WY and Wells NE}. The model results in Table 12.8 show the results for Rock Springs WY, with one set of weights {0, 0.75, 0.25, 0} yielding Rock Springs with a greater functional value than any of the other 11 alternatives. The weights yielding Wells NE as nondominated had all the weight on Lives Lost.

Table 12.8 Output for stochastic model for Rock Springs WY

Object	Rock Springs WY	36.322	100	80	80	94.99304
Weights		0.0001	0.7499	0.24993	0.0001	1
	Nome AK	67.170	80	0	25	59.999
	Newark NJ	9.158	0	100	100	25.004
	Duquesne PA	50.272	100	50	50	87.494
	Gary IN	40.660	60	80	80	64.999
	Yakima Flats WA	38.858	60	30	30	52.497
	Turkey TX	47.538	90	30	30	74.994
	Wells NE	57.170	110	50	50	94.993
	Anaheim CA	21.514	10	0	0	7.501
	Epcot Center FL	32.418	20	100	100	40.004
	Duckwater NV	29.158	70	50	50	64.995
	Santa Cruz CA	21.514	40	0	0	29.997

One of the alternatives that was nondominated with deterministic data {Nome AK} was found to be dominated with stochastic data. Table 12.9 shows the results for the original deterministic model for Nome AK.

The stochastic results are shown in Table 12.10:

Wells NE is shown to be superior to Nome AK at the last set of weights the SOLVER algorithm in EXCEL attempted. Looking at the stochastically adjusted

Table 12.9 Nome AK alternative results with original model

Object	Nome AK	60	80	0	25	64.9857
Weights		0.7500	0.2498	0.0001	0.0001	1
	Newark NJ	0	0	100	100	0.020
	Rock Springs WY	40	100	80	80	54.994
	Duquesne PA	40	100	50	50	54.988
	Gary IN	30	60	80	100	37.505
	Yakima flats WA	30	60	30	50	37.495
	Turkey TX	40	90	30	80	52.491
	Wells NE	50	110	50	50	64.986
	Anaheim CA	10	10	0	0	9.998
	Epcot center FL	20	20	100	0	20.006
	Duckwater NV	20	70	50	25	32.492
	Santa Cruz CA	10	40	0	0	17.491

Table 12.10 Nome AK alternative results with stochastic model

Object	Nome AK	55.97	80	0	25	55.965
Weights		0.9997	0.0001	0.0001	0.0001	1
	Newark NJ	9.009	0	100	100	9.027
	Rock Springs WY	47.170	100	80	80	47.182
	Duquesne PA	50.403	100	50	50	50.408
	Gary IN	41.034	60	80	100	41.046
	Yakima Flats WA	39.305	60	30	50	39.307
	Turkey TX	47.715	90	30	80	47.721
	Wells NE	**57.356**	**110**	**50**	**50**	**57.360**
	Anaheim CA	21.631	10	0	0	21.625
	Epcot Center FL	32.527	20	100	0	32.529
	Duckwater NV	29.305	70	50	25	29.310
	Santa Cruz CA	21.631	40	0	0	21.628

scores for cost, Wells NE now has a superior cost value to Nome AK (the objective functional cost value is penalized downward, the constraint cost value for Wells NE and other alternatives are penalized upward to make a harder standard to meet).

DEA Models

DEA evaluates alternatives by seeking to maximize the ratio of efficiency of output attainments to inputs, considering the relative performance of each alternative. The mathematical programming model creates a variable for each output (outputs designated by u_i) and input (inputs designated by v_j). Each alternative k has performance coefficients for each output (y_{ik}) and input (x_{jk}). The classic Charnes, Cooper and Rhodes (CCR)[19] DEA model is:

$$\text{Max efficiency}_k = \frac{\sum_{i=1}^{2} u_i y_{ik}}{\sum_{i=1}^{2} u_j x_{jk}}$$

s.t. For each k from 1 to 12:

$$\frac{\sum_{i=1}^{2} u_i y_{ik}}{\sum_{j=1}^{2} v_i x_{jk}} \leq 1$$

$$u_i, v_j \geq 0$$

The Banker, Charnes and Cooper (BCC) DEA model includes a scale parameter to allow of economies of scale. It also releases the restriction on sign for u_i, v_j.

$$\text{Max efficiency}_k = \frac{\sum_{i=1}^{2} u_i y_{ik} + y}{\sum_{i=1}^{2} v_j x_{jk}}$$

s.t. For each k from 1 to 12:

$$\frac{\sum_{i=1}^{2} u_i y_{ik} + v}{\sum_{j=1}^{2} v_j x_{jk}} \leq 1$$

$$u_i, v_j \geq 0, \gamma \text{ unrestricted in sign}$$

A third DEA model allows for super-efficiency. It is the CCR model without a restriction on efficiency ratios.

$$\text{Max efficiency}_k = \frac{\sum_{i=1}^{2} u_i y_{ik}}{\sum_{j=1}^{2} v_j x_{jk}}$$

s.t. For each l from 1 to 12:

$$\frac{\sum_{i=1}^{2} u_i y_{il}}{\sum_{j=1}^{2} v_j x_{jl}} \leq 1 \text{ for } l \neq k$$

$$u_i, v_j \geq 0$$

The traditional DEA models were run on the dump site selection model, yielding results shown in Table 12.11.

These approaches provide rankings. In the case of CCR DEA, the ranking includes some ties (for first place and 11th place). The nondominated Nome AL alternative was ranked 10th, behind dominated solutions Turkey TX, Duquesne PA, Yakima Flats WA, and Duckwater NV. Nome dominates Anaheim CA and Santa Cruz CA, but does not dominate any other alternative. The ranking in 10th place is probably due to the smaller scale for the Cost criterion, where Nome AK has the best score. BCC DEA has all dominated solutions tied for first. The rankings for 7th through 12 reflect more of an average performance on all criteria (affected by scales). The rankings provided by BCC DEA after first are affected by criteria scales. Super-CCR provides a nearly unique ranking (tie for 11th place).

Conclusions

The importance of risk management has vastly increased in the past decade. Value at risk techniques have been becoming the frontier technology for conducting

Table 12.11 Traditional DEA model results

	CCR DEA		BCC DEA		Super-CCR	Super-CCR
Alternative	Score	Rank	Score	Rank	Score	Rank
Nome AK	0.43750	10	1	1	0.43750	10
Newark NJ	0.75000	6	1	1	0.75000	6
Rock Springs WY	1	1	1	1	1.31000	1
Duquesne PA	0.62500	7	0.83333	8	0.62500	7
Gary IN	1	1	1	1	1.07143	2
Yakima Flats WA	0.5	8	0.70129	9	0.5	8
Turkey TX	0.97561	3	1	1	0.97561	3
Wells NE	0.83333	5	1	1	0.83333	5
Anaheim CA	0	11	0.45000	12	0	11
Epcot Center FL	0.93750	4	1	1	0.93750	4
Duckwater NV	0.46875	9	0.62500	10	0.46875	9
Santa Cruz CA	0	11	0.48648	11	0	11

enterprise risk management. One of the ERM areas of global business involving high levels of risk is global supply chain management. This paper has developed a new approach called "DEA VaR" for selection of alternatives in ERM. This is a simplified version of existing stochastic DEA models. Thus, the main purpose of this paper is to review and present new ERM approaches.

Selection in supply chains by its nature involves the need to trade off multiple criteria, as well as the presence of uncertain data. When these conditions exist, stochastic dominance can be applied if the uncertain data is normally distributed. If not normally distributed, simulation modeling applies (and can also be applied if data is normally distributed).

DEA VaR can help to improve a performance measurement system in supply chain management. When the data is presented with uncertainty, stochastic DEA provides a good tool to perform efficiency analysis by handling both inefficiency and stochastic error. We must point out the main difference for implementing a investment VaR in financial markets such as banking industry and our DEA VaR used for supplier selection: the underlying asset volatility or standard deviation is typically a managerial assumption due to lack of sufficient historical data to calibrate the risk measure.

Notes

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Chapter 13

Portfolio Selection Under Fuzzy and Stochastic Uncertainty

Portfolio selection models are usually a must in the process of diagnosing risk exposures. This chapter presents portfolio selection under fuzzy and stochastic uncertainty. Portfolio selection regards asset selection which maximizes an investor's return and minimizes her risk. In 1952, Markowitz[1] published his pioneering work and laid the foundation of modern portfolio analysis. The core of the Markowitz mean variance model is to take the expected return of a portfolio as investment return and the variance of the expected return of a portfolio as investment risk. The main input data of the Markowitz mean variance model are expected returns and variance of expected returns of these securities. However, Markowitz's mean variance framework has been criticized due to several drawbacks.[2] This framework employs the variance of the portfolio return as the only security risk measure. Controlling (minimizing) the variance imposes bounds on both downside and upside deviation from the expected return, which may limit possible gains. A large literature on Markowitz's mean variance framework exists.[3]

Another popular portfolio selection model is safety-first portfolio models originated from Roy.[4] This set of models help investors look at only a low-risk portfolio that offers some modest growth potential.[5] There are also vast numbers of portfolio models using safety-first models.[6] Both Markowitz's mean variance framework and safety-first portfolio models and a great deal of extensions are based on probability theory, where the theory of expected utility is usually used derived from a set of axioms concerning investor behavior as regards the ordering relationship for deterministic and random events in the choice set. In other words, it is assumed that a probability measure can be defined on the random outcomes. However, if the origins of such random events are not well known, then the probability theory becomes inadequate because of a lack of experimental information.[7]

In a complicated financial market, some financial variables can exhibits random uncertainty property, while others can exhibits fuzzy uncertainty property. Fuzzy set theory has been widely used to solve many financial risk management problems since the 1960s. For example, Bellman and Zadeh[8] proposed fuzzy decision theory. Ramaswamy[9] presented a fuzzy bond portfolio selection, where fuzzy return-risk tradeoff is analyzed for an assumed market scenario. The uncertainty can be of two kinds, random uncertainty and fuzzy uncertainty. Random uncertainty is the

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uncertainty that whether the event will happen or not, which means it's hard to predict whether the event will be happening or not. However, the states of the event are clear, thus its external uncertainty. Fuzzy uncertainty is the uncertainty of the states of that event itself, that is, the problem does not rest with the event's happening but rests with the states of the event being unclear. It leads to different people having different feelings on observing the same event, so deducing different conclusions, so fuzzy uncertainty can encapsulate subjective uncertainty. Katagiri and Ishii[10] first supposed the security's future return was fuzzy random variable and did some research on fuzzy random assets portfolio selection problem. Wu provided basic fuzzy models.[11]

Fuzzy Random Variables

Roughly speaking, a fuzzy random variable is a measurable function from a probability space to a collection of fuzzy variables. In other words, a fuzzy random variable is a random variable taking fuzzy values. We use fuzzy random variables to describe the hybrid uncertainty in the security market. Basic fuzzy random variable definitions can be found in Campos and Gonzalez.[12] We use alpha-cuts[13] to transform trapezoidal fuzzy random variables into uniformly distributed fuzzy random variables.

Expected Value for a Fuzzy Random Variable

Fuzzy expected value reflects the center value that the fuzzy random variable tends to, describing the fuzzy random variable's statistical property, which has important effect in decision making.

The λ Mean Ranking Method

Let $\tilde{M}$ be a fuzzy number, its α-cut set is $\tilde{M}_\alpha = [M_\alpha^-, M_\alpha^+]$. The fuzzy number $\tilde{M}$'s λ mean is defined as

$$V^\lambda(\tilde{M}) = \int_0^0 [\lambda \tilde{M}_\alpha^+ + (1-\lambda)\tilde{M}_\alpha^-] \mathrm{d}\alpha$$

where the parameter $\lambda \in [0,1]$ reflects the DM's subjective optimistic-pessimistic degree.

The parameter $\lambda = 1$ expresses that DM is totally optimistic about all of the maximal value (delegate the maximal possible return). Contrarily, the parameter $\lambda = 0$ expresses that DM is totally pessimistic (delegate the minimal possible return). If the parameter $\lambda = 0.5$, it expresses that the investor's attitude is relative neutral. Generically, if the DM is relative optimistic, then the parameter could be a little larger number, Contrarily, if the DM is relative pessimistic, then the parameter could be a little smaller number. Through changing the value of parameter $\lambda \in [0,1]$, the DM's degree of optimism-pessimism can be reflected.

Example The sum of two trapezoidal fuzzy numbers is also a trapezoidal fuzzy number, and the product of a trapezoidal fuzzy number and a scalar number is also a trapezoidal fuzzy number. The sum of $\tilde{a} = (a_1, a_2, a_3, a_4)$ and $\tilde{b} = (b_1, b_2, b_3, b_4)$ is defined as $\tilde{a} + \tilde{b} = (a_1 + b_1, a_2 + b_2, a_3 + b_3, a_4 + b_4)$. We also have

$$k\tilde{a} = \begin{cases} (ka_1, ka_2, ka_3, ka_4), k > 0 \\ (ka_4, ka_3, ka_2, ka_1), k < 0. \end{cases}$$

Now let us consider two trapezoidal fuzzy numbers $\tilde{r} = (r_1, r_2, r_3, r_4)$ and $\tilde{b} = (b_1, b_2, b_3, b_4)$, then the possibility value of the first trapezoidal fuzzy number being no larger than the second is defined as:

$$\text{Pos}\{\tilde{r} \le \tilde{b}\} = \begin{cases} 1, & r_2 \le b_3; \\ \dfrac{b_4 - r_1}{b_4 - b_3 + r_2 - r_1}, & r_2 \ge b_3, r_1 \le b_4; \\ 0, & r_1 \le b_4. \end{cases}$$

Specifically, when $\tilde{b}$ takes a crisp value of 0, the definition is simplified as

$$\text{Pos}\{\tilde{r} \le 0\} = \begin{cases} 1, & r_2 \le 0; \\ \dfrac{r_1}{r_1 - r_2}, & r_1 \le 0 \le r_2; \\ 0, & r_1 \ge 0. \end{cases}$$

Let $\tilde{M}$, $\tilde{N}$ be fuzzy numbers, and their λ-means are $V^{\lambda}(\tilde{M})$, $V^{\lambda}(\tilde{N})$, for if $V^{\lambda}(\tilde{M}) \ge V^{\lambda}(\tilde{N})$, we deduce that the fuzzy number $\tilde{M}$ is larger than $\tilde{N}$ on the meaning of λ-mean, denoted as $\tilde{M} \ge_{\lambda} \tilde{N}$.

This definition provides a tool to rank fuzzy numbers by use of λ-means of fuzzy numbers.

Hybrid Entropy[14]

Let $D(X)$ be the collectivity of sets on discrete universe of discourse $X = \{x_i | i = 1, 2, \ldots, n\}$, A $\in D(X)$, denoted as $A = \sum_{i=1}^{n} \mu_i / x_i, \forall x_i \in X$, wherein $\mu(x_i)$ is the membership of x_i subjects to A, and the range is [0,1]. Let $M = (\mu_1, \mu_2, \ldots, \mu_n)$, called the possibility distribution of fuzzy set A, and the probability distribution on the universe of discourse X is $P = (p_1, p_2, \ldots, p_n)$, where the p_i is the frequency of x_i. We define the hybrid set as $\overline{A}(P, M) = \sum_{i=1}^{n} p_i \mu_i / x_i, \forall x_i \in X$, recorded as $\overline{A}(P, M) = \overline{A}$. Then we call

$$F(\overline{A}) = -\sum_{i=1}^{n} \{p_i \mu_i \log p_i \mu_i + p_i (1 - \mu_i) \log p_i (1 - \mu_i)\}$$

the hybrid entropy of the hybrid set $\overline{A}$.

Possibility Theory

Possibility theory was proposed by Zadeh[15] and advanced by Dubois and Prade[16] where fuzzy variables are associated with possibility distributions in a similar way that random variables are associated with probability distributions in probability theory. The possibility distribution function of a fuzzy variable is usually defined by the membership function of the corresponding fuzzy set. We call a fuzzy number $\tilde{a}$ of any fuzzy subset R with membership function $\mu_a{:}R \to [0,1]$. Let $\tilde{a}$, $\tilde{b}$ be two fuzzy numbers with membership function $\mu_a(x)$, $\mu_b(x)$, respectively. Based on the concepts and techniques of possibility theory founded by Zadeh,[17] we consider in this paper the trapezoidal fuzzy numbers which are fully determined by quadruples $\tilde{r} = (r_1, r_2, r_3, r_4)$of crisp numbers such that $r_1 \le r_2 \le r_3 \le r_4$. Their membership functions can be denoted by:

$$\mu(x) = \begin{cases} \dfrac{x - r_1}{r_2 - r_1}, & r_1 \le x < r_2 \\ 1, & r_2 \le x \le r_3 \\ \dfrac{x - r_4}{r_3 - r_4}, & r_3 \le x \le r_4 \\ 0, & \text{otherwise} \end{cases}$$

We note that the trapezoidal fuzzy number is a triangular fuzzy number if $r_2{=}r_3$.

Possibilistic Mean Value and Variance

The α-level set of a fuzzy number $\tilde{r} = (r_1, r_2, r_3, r_4)$ is a crisp subset of R and is denoted by $[\tilde{r}]^\alpha = \{x|\mu(x) \ge \alpha, x \in R\}$. For the trapezoidal fuzzy number,

$$[\tilde{r}]^\alpha = \{x|\mu(x) \ge \alpha, x \in R\} = [r_1 + \alpha(r_2 - r_1), \mathrm{r}_4 - \alpha(r_4 - r_3)].$$

Carlsson et al.[18] introduced the notation of crisp possibilitic mean value of continuous possibility distributions, which are consistent with the extension principle. Let $[\tilde{r}]^\alpha = [a_1(\alpha), a_2(\alpha)]$, then the crisp possibilistic mean value of $\tilde{r} = (r_1, r_2, r_3, r_4)$ is computed as

$$E(\tilde{r}) = \int_0^1 \alpha(a_1(\alpha) + a_2(\alpha))\mathrm{d}\alpha.$$

It is easy to see that if $\tilde{r} = (r_1, r_2, r_3, r_4)$ is a trapezoidal fuzzy number then

$$E(\tilde{r}) = \int_0^1 \alpha(r_1 + \alpha(r_2 - r_1) + r_4 - \alpha(r_4 - r_3))\mathrm{d}\alpha = \frac{r_2 + r_3}{3} + \frac{r_1 + r_4}{6},$$

giving the crisp possibilistic variance value of $\tilde{r} = (r_1, r_2, r_3, r_4)$ as $\sigma(\tilde{r}) = \frac{1}{2}\int_0^1 \alpha(a_2(\alpha) - a_1(\alpha))^2 \mathrm{d}\alpha$.
Then the crisp possibilistic covariance value of $\tilde{a} = (a_1, a_2, a_3, a_4)$ and $\tilde{b} = (b_1, b_2, b_3, b_4)$ can be computed as $\mathrm{cov}(\tilde{a},\tilde{b}) = \frac{1}{2}\int_0^1 \alpha(a_2(\alpha) - a_1(\alpha))(b_2(\alpha) - b_1(\alpha))d\alpha$. Based on this, it is easy to see that if $\tilde{a} = (a_1, a_2, a_3, a_4)$ and $\tilde{b} = (b_1, b_2, b_3, b_4)$ are two trapezoidal fuzzy numbers, then we have:

$$\begin{aligned}\mathrm{cov}(\tilde{a},\tilde{b}) = {} & \frac{(a_3-a_2)(b_3-b_2)}{8} + \frac{(a_4-a_1)(b_4-b_1)}{24} \\ & + \frac{(a_3-a_2)(b_4-b_1)}{24} + \frac{(a_4-a_1)(b_3-b_2)}{24},\end{aligned}$$

and

$$\sigma(\tilde{a}) = \frac{(a_3-a_2)^2}{8} + \frac{(a_4-a_1)^2}{24} + \frac{(a_3-a_2)(a_4-a_1)}{12}.$$

Mean Variance Portfolio Selection Model with Safety-First

Mean Variance Model and Mean Safety-First Model

Suppose we have m risky securities, the risk tolerance factor of the investor is set to be t, r_j is the expected returns of security j, σ_{ij} is the covariance of the expected returns on security i and j, the investor chooses a proportion x_i of her wealth to invest in security i so that the total expected returns can be maximized and total variance can be minimized. This portfolio selection problem in the mean variance context can be written as (MV)[19]:

$$(\mathrm{MV}) \quad \begin{cases} \max f(x) = \sum\limits_j r_j x_j \\ \min g(x) = \sum\limits_{\mathrm{i}} \sum\limits_j \sigma_{ij} x_i x_j \\ \text{s.t.} \quad \sum\limits_{i=1}^{m} x_i = 1 \\ \qquad 0 \le x_i \le \alpha_i (i = 1, 2, \ldots, m) \end{cases}$$

where α_i is the upper bound for x_i. Suppose the risk tolerance factor of the investor is t, we can then transform the two-objective programming into a single objective programming by replacing the second objective with $\sum_i \sum_j \sigma_{ij} x_i x_j \le t$. Obviously, the greater the factor t is, the more risk tolerance the investor has. The objective function $f(x)$ and $g(x)$ are also functions of the expected return and variance.

A mean safety-first efficient portfolio can be obtained by replacing the variance objective with a probability objective in the above programming model, where the investor maximizes the total expected value of his/her portfolio, which requires the probability that the expected value of his portfolio no smaller than a given parameter. The following optimization problem gives a mean safety-first efficient portfolio model[20]:

$$\text{(MSF)} \quad \begin{cases} \max f(x) = \sum\limits_{j=1}^{n} r_j x_j \\ \text{s.t.} \quad P(\sum\limits_{j=1}^{n} r_j x_j \leq u) \leq \beta \\ \qquad \sum\limits_{i=1}^{n} x_i = 1 \\ \qquad 0 \leq x_i \leq \alpha_i (i = 1,2,\ldots,n) \end{cases}$$

Where a given parameter β is used as the upper bound for the probability, u is used as the upper bound for the total expect return, x_i and α_i are the same as before.

In standard portfolio models uncertainty is handled in the form of randomness using probability theory. One of the main difference between the possibility and probability measures is that probability is additive whereas possibility is subadditive, which means for the possibility measure that the possibility of an event being partitioned into smaller events, is less than or equal to the sum of the possibilities of the smaller events. The subadditive property of the possibility measure fits the requirements of risk metrics in financial theory.[21] Using probability theory can hardly account for the uncertainty in the probability distribution of the uncertain variables. In contrast, measurement of the uncertainty in a possibilistic model can be done by the sum of the possibilities of an event and its complement minus one. A fuzzy mean variance safety-first portfolio selection model can be easily yielded by combing the mean variance portfolio selection model and safety-first portfolio selection model and replacing the exact numbers with fuzzy numbers, e.g., the trapezoidal fuzzy number or triangular fuzzy number.

Hybrid Entropy Based Portfolio Selection

Return Optimization

Let r_i denote the return rate of the ith stock, x_i is the investment scale of the ith stock. Suppose the return rate of the ith stock is a triangular fuzzy random variable, denoted by $\tilde{\bar{r}}_i$, and its membership function is as follows, for some $\omega \in \Omega$,

$$\mu_{\tilde{\bar{r}}_i}(\omega)(x) = \begin{cases} \dfrac{\alpha_i - a_i(\omega) + x}{\alpha_i}, & a_i(\omega) - \alpha_i < x < a_i(\omega), \\ 1, & x = a_i(\omega), \\ \dfrac{\beta_i + a_i(\omega) - x}{\beta_i}, & a_i(\omega) < x < a_i(\omega) + \beta_i. \end{cases}$$

Here $\alpha_i,\beta_i(> 0)$ is the left and right width of the fuzzy number, and a_i is assumed to be a normally distributed random variable with distribution $a_i \sim N(E(a_i), \sigma_i^2)$, where $E(a_i)$ is its expected value, and σ_i^2 the variance.

We express the fuzzy random variable $\tilde{\bar{r}}_i$ as $\tilde{\bar{r}}_i(\omega) = (a_i(\omega) - \alpha_i, a_i(\omega), a_i(\omega) + \beta_i)$, $\forall\omega \in \Omega$. Now we need to obtain the parameters of the fuzzy random variable $\tilde{\bar{r}}_i$, $\alpha_i, \beta_i, E(a_i)$. We could know the left and right width α_i, β_i, $i = 1,2,\ldots,n$ according to experts' opinions, and we can use the following method to generate these: choose some experts, let them give the left and right width, denoted as α_i^k and β_i^k, then adopt an arithmetic average method to obtain α_i and β_i, that is $\alpha_i = \sum_{k=1}^K \alpha_i^k/K$, $\beta_i = \sum_{k=1}^K \beta_i^k/K$. $E(a_i)$ could be obtained similar to the classical mean-variance model (Markowitz 1952), that is, collecting some data of a period in the past, using historical return rate to substitute $E(a_i)$ here.

According to the assumption, the portfolio's future return rate could be described by fuzzy random variable $\sum_{i=1}^n \tilde{\bar{r}}_i x_i$. Particularly, for a certain $\omega \in \Omega$, $\sum_{i=1}^n \tilde{\bar{r}}_i(\omega) x_i$ is a triangular fuzzy number, so $\tilde{\bar{r}}_i(\omega)$'s α-cut set is

$$(\tilde{\bar{r}}_i(\omega))_\alpha = [(\tilde{\bar{r}}_i(\omega))_\alpha^-,(\tilde{\bar{r}}_i(\omega))_\alpha^+] = [a_i(\omega) - (1-\alpha)\alpha_i, a_i(\omega) + (1-\alpha)\beta_i].$$

From Wu (2009),[22] we have:

$$(E(\tilde{\bar{r}}_i))_\alpha = [E((\tilde{\bar{r}}_i(\omega))_\alpha^-), E((\tilde{\bar{r}}_i(\omega))_\alpha^+)] = [E(a_i) - (1-\alpha)\alpha_i, E(a_i) + (1-\alpha)\beta_i].$$

The expected value $E(\tilde{\bar{r}}_i)$ of fuzzy random variable $\tilde{\bar{r}}_i$ is a triangular fuzzy number,

$$E(\tilde{\bar{r}}_i) = (E(a_i) - \alpha_i, E(a_i), E(a_i) + \beta_i), \quad x_i \geq 0, \quad i = 1,2,\ldots n.$$

Also from Wu (2009), the expected value of the return of the portfolio $\sum \tilde{\bar{r}}_i x_i$ is:

$$E\left(\sum_{i=1}^n \tilde{\bar{r}}_i x_i\right) = \sum_{i=1}^n E(\tilde{\bar{r}}_i) x_i = \left(\sum_{i=1}^n E(a_i) x_i, \sum_{i=1}^n \alpha_i x_i, \sum_{i=1}^n \beta_i x_i\right).$$

In order to compare the fuzzy random variables $\sum \tilde{\bar{r}}_i x_i$, we compare the expected values of the fuzzy random variables $E\left(\sum \tilde{\bar{r}}_i x_i\right)$, which is a fuzzy number. We then use the λ mean ranking method (Wu 2009) to rank these fuzzy numbers $E\left(\sum \tilde{\bar{r}}_i x_i\right)$.

We denote the parameter vector as$\lambda = (\lambda_1, \lambda_2, \ldots, \lambda_n)$, where the component of λ_i reflects the investor's optimistic-pessimistic degree for the ith security. Derived from definition 8, the λ-mean of $E\left(\sum \tilde{\bar{r}}_i x_i\right)$ is:

$$V^{\lambda}\left(E\left(\sum\nolimits_{i=1}^{n}\tilde{\bar{r}}_i x_i\right)\right)=\sum\nolimits_{i=1}^{n}[E(a_i)+\lambda_i\beta_i\int_0^1(1-\alpha)\mathrm{d}\alpha-(1-\lambda_i)\alpha_i\int_0^1(1-\alpha)\mathrm{d}\alpha]x_i$$
$$=\sum\nolimits_{i=1}^{n}[E(a_i)+\lambda_i\beta_i/2-(1-\lambda_i)\alpha_i/2]x_i$$

To maximize the investment return of selected securities with hybrid uncertainties, we can maximize the fuzzy expected value of the portfolio, which leads to the first objective function in our proposed model:

Objective 1

$$\max \quad V^{\lambda}\left(E\left(\sum\nolimits_{i=1}^{n}\tilde{\bar{r}}_i x_i\right)\right) \tag{1}$$

To reduce the computation complexity in (1), we assume the future return rate $\tilde{\bar{r}}_i$ of every stock is the triangular fuzzy random variable, denoted by $\tilde{\bar{r}}_i=(a_i-\alpha_i,a_i,a_i+\beta_i)$, with the expression of object 1 simplified to:

$$\max \quad \sum\nolimits_{i=1}^{n}[E(a_i)+\lambda_i\beta_i/2-(1-\lambda_i)\alpha_i/2]x_i \tag{2}$$

Risk Modeling: We now give the definition of hybrid entropy risk. If the return of security $\bar{A}$ is discrete fuzzy random variable, then the risk of $\bar{A}$ is:

$$F(\bar{A})=-\sum\nolimits_{t=1}^{T}\{p(r_t)\mu(r_t)\log p(r_t)\mu(r_t)+p(r_t)(1-\mu(r_t))r_t\log p(r_t)(1-\mu(r_t))\}$$

wherein $0\le p(r_t)\le 1,\sum\nolimits_{t=1}^{T}p(r_t)=1,\mu(r_t)\in[0,1]$, r_t is the return of the tth day of the security.

When $\mu(r_t)=\{0,1\}$, the expression of the hybrid entropy risk value degenerates. As the definition in this form is more general, it can describe the random and fuzzy uncertainty uniformly.

$F(\bar{A})$ denotes the average information value of the security. When $p(r_t)=0$ or $\mu(r_t)=0$, the limit value of $F(\bar{A})$ is 0. For a positive value, a larger value of $F(\bar{A})$ means greater degree of uncertainty of obtaining the return, i.e., higher risk. In contrast, for a negative value, a smaller value of $F(\bar{A})$ means greater degree of uncertainty of obtaining the return, i.e., higher risk. When $F(\bar{A})=0$, the risk is the lowest. Denote by $F(d)$ the distance between $F(\bar{A})$ and 0, it is obvious that a larger value of $F(d)$ indicates a higher risk and vice versa.

Suppose the investor invests in n securities, with the weights of the ith ($i=1,2,\ldots,n$) security being x_i, then the risk of the portfolio of these securities is

$$f(F(d){:}x_1,x_2,\ldots,x_n)=\sum\nolimits_{i=1}^{n}x_iF_i(d) \tag{3}$$

where $x_i\ge 0$, $F_i(d)$ is the investment risk of the ith security.

To minimize the portfolio risk in (3), we have Objective 2:

Objective 2 (Minimizing the portfolio risk):

$$\min f(F(d){:}x_1, x_2, \ldots, x_n) = \min \sum\nolimits_{i=1}^{n} x_i F_i(d) \tag{4}$$

λ Mean-hybrid entropy model: Taking both Object 1 and 2 into consideration, we have the following portfolio selection model:

$$\begin{aligned} \max \quad & f_1 = V^{\lambda}(E(\sum_{i=1}^{n} \tilde{\bar{r}}_i x_i)) \\ \min \quad & f_2 = f(F(d){:}x_1, x_2, \ldots, x_n) \\ \text{s.t.} \quad & \sum_{i=1}^{n} x_i = 1, \\ & x_i \geq 0, i = 1{,}2, \ldots n. \end{aligned} \tag{5}$$

which can be expressed as:

$$\begin{aligned} \max \quad & f_1 = \sum_{i=1}^{n} [E(a_i) + \lambda_i \beta_i/2 - (1 - \lambda_i)\alpha_i/2] x_i \\ \min \quad & f_2 = \sum_{i=1}^{n} x_i F_i(d) \\ \text{s.t.} \quad & \sum_{i=1}^{n} x_i = 1, \\ & x_i \geq 0, \quad i = 1, 2, \ldots n. \end{aligned} \tag{6}$$

We denote by $X = \left\{ x \in R | \sum_{i=1}^{n} x_i = 1, x_i \geq 0, i = 1, 2, \ldots n \right\}$ the feasible regions of the problem (8).

Remark 1 The mean-hybrid model (5) allows investors to have different anticipations of the future expected return, where the parameter λ reflects the optimistic-pessimistic degree of every stock. This is essentially different from the assumption of Markowitz framework where the investors must have the same anticipation. Our model breaks through this assumption by introducing the optimistic-pessimistic parameter which reflects differing anticipation of different investors.

Remark 2 When $\alpha_i = \beta_i = 0$, $i = 1, 2, \ldots, n$, the first objective of Model (6) is as the same as the object of return in the classical Markowitz model, and when the membership function $\mu(r_t)$ equals 1 or 0, then the object 2 of this model is as same as the object of risk in a mean-entropy model. In these terms, this model is an extensive model.

Numerical Example

This section presents a numerical example for a 20-security problem to demonstrate our proposed approach.

Let us consider a 20-securites problem with the possibility distribution given in Table 13.1.

Table 13.1 Possibility distribution

Security	Trapezoid data			
1→4	0.06,0.09,0.17,0.25	0.1,0.12,0.25,0.31	0.05,0.09,0.17,0.34	0.04,0.1,0.19,0.37
5→8	0.01,0.13,0.27,0.41	0.03,0.1,0.25,0.43	0.01,0.1,0.2,0.39	0.01,0.08,0.16,0.31
9→112	0.01,0.05,0.15,0.32	0.01,0.07,0.17,0.33	0.02,0.11,0.19,0.37	0.05,0.09,0.24,0.49
13→16	0.01,0.07,0.16,0.34	0.02,0.13,0.32,0.59	0.04,0.08,0.15,0.32	0.06,0.11,0.26,0.54
17→20	0.01,0.12,0.31,0.61	0.01,0.06,0.31,0.57	0.03,0.11,0.5,0.91	0.02,0.08,0.25,0.51

The manager structuring an equity portfolio only have vague views regarding equity return scenarios described as “bullish”, “bearish” or “neutral”. The manager forms such views as a result of the subjective or intuitive opinion of the decision-maker on the basis of information available at a given point in time. It is recognized that a fuzzy set can be used to characterize the range of acceptable solutions to the portfolio selection problem under this circumstance. Therefore, the manager may specify the possibility distribution for expected rates in Table 13.1.

The above trapezoidal fuzzy data can also be obtained by fuzzifying historical stochastic data. The approach for stating vague input data using historical data is similar to an interesting and practically applicable method based on historical data quantile.[23] Parameters such as return, risks, and skewness are derived from standard error of historical values and normal density function of error is assumed as an approximation. For example, based on probability theory, suppose the mean and standard error (S.E.) of the first security are $\mu = 18\%$ and $\sigma = 3\%$. The following formula is used to transform this historical stochastic data into Trapezoidal fuzzy data: $a_1 = \mu - 2\sigma$, $a_2 = \mu - \sigma$, $a_3 = \mu + \sigma$ and $a_4 = \mu + 2\sigma$, where μ and σ are mean and S.E. standard error of related historical data. The deviation of one times S.E. for a_2 and a_3 corresponds to 34.1% quantile and 2 times S.E. for a_1 and a_4 corresponds to 47.7% quantile.

Similarly, trapezoidal fuzzy data in Table 13.1 can be yielded by fuzzifying either qualitative data or historical stochastic data or both. Using above formulas, the fuzzy mean and fuzzy variance and co-variance are calculated for these 20 securities. The fuzzy mean values are:

$$E(\tilde{r}) = [13.83\ 19.167\ 15.17\ 16.5\ 20.33\ 19.33\ 16.67\ 13.33\ 12.17\ 13.67\ 16.5\ 20$$
$$13.5\ 25.17\ 13.67\ 22.33\ 24.67\ 22\ 36\ 19.8]$$

The fuzzy variance-covariance matrix of these 20 securities can be computed in percentage:

$$\begin{pmatrix}
0.36 & 0.47 & 0.47 & 0.53 & 0.70 & 0.72 & 0.61 & 0.48 & 0.53 & 0.54 & 0.54 & 0.76 & 0.53 & 0.98 & 0.44 & 0.81 & 1.02 & 1.08 & 1.69 & 0.86 \\
0.47 & 0.62 & 0.61 & 0.69 & 0.92 & 0.94 & 0.79 & 0.63 & 0.69 & 0.70 & 0.70 & 1.00 & 0.69 & 1.28 & 0.57 & 1.06 & 1.33 & 1.42 & 2.22 & 1.12 \\
0.47 & 0.61 & 0.62 & 0.71 & 0.93 & 0.95 & 0.81 & 0.64 & 0.70 & 0.71 & 0.72 & 1.01 & 0.71 & 1.30 & 0.59 & 1.07 & 1.34 & 1.42 & 2.22 & 1.13 \\
0.53 & 0.69 & 0.71 & 0.80 & 1.05 & 1.08 & 0.92 & 0.73 & 0.79 & 0.81 & 0.81 & 1.15 & 0.80 & 1.47 & 0.67 & 1.22 & 1.53 & 1.61 & 2.52 & 1.28 \\
0.70 & 0.92 & 0.93 & 1.05 & 1.38 & 1.41 & 1.20 & 0.95 & 1.04 & 1.06 & 1.06 & 1.50 & 1.05 & 1.93 & 0.87 & 1.59 & 2.00 & 2.11 & 3.31 & 1.68 \\
0.72 & 0.94 & 0.95 & 1.08 & 1.41 & 1.45 & 1.23 & 0.97 & 1.06 & 1.09 & 1.09 & 1.54 & 1.08 & 1.98 & 0.89 & 1.63 & 2.05 & 2.17 & 3.40 & 1.73 \\
0.61 & 0.79 & 0.81 & 0.92 & 1.20 & 1.23 & 1.04 & 0.83 & 0.90 & 0.92 & 0.93 & 1.31 & 0.92 & 1.68 & 0.76 & 1.39 & 1.74 & 1.83 & 2.87 & 1.46 \\
0.48 & 0.63 & 0.64 & 0.73 & 0.95 & 0.97 & 0.83 & 0.66 & 0.72 & 0.73 & 0.73 & 1.03 & 0.73 & 1.33 & 0.60 & 1.10 & 1.38 & 1.45 & 2.27 & 1.16 \\
0.53 & 0.69 & 0.70 & 0.79 & 1.04 & 1.06 & 0.90 & 0.72 & 0.78 & 0.80 & 0.80 & 1.13 & 0.79 & 1.46 & 0.66 & 1.20 & 1.51 & 1.59 & 2.49 & 1.27 \\
0.54 & 0.70 & 0.71 & 0.81 & 1.06 & 1.09 & 0.92 & 0.73 & 0.80 & 0.82 & 0.82 & 1.16 & 0.81 & 1.49 & 0.67 & 1.23 & 1.54 & 1.63 & 2.55 & 1.30 \\
0.54 & 0.70 & 0.72 & 0.81 & 1.06 & 1.09 & 0.93 & 0.73 & 0.80 & 0.82 & 0.82 & 1.16 & 0.81 & 1.49 & 0.67 & 1.23 & 1.54 & 1.62 & 2.54 & 1.30 \\
0.76 & 1.00 & 1.01 & 1.15 & 1.50 & 1.54 & 1.31 & 1.03 & 1.13 & 1.16 & 1.16 & 1.64 & 1.15 & 2.11 & 0.95 & 1.74 & 2.18 & 2.30 & 3.61 & 1.84 \\
0.53 & 0.69 & 0.71 & 0.80 & 1.05 & 1.08 & 0.92 & 0.73 & 0.79 & 0.81 & 0.81 & 1.15 & 0.80 & 1.47 & 0.67 & 1.22 & 1.53 & 1.61 & 2.52 & 1.28 \\
0.98 & 1.28 & 1.30 & 1.47 & 1.93 & 1.98 & 1.68 & 1.33 & 1.46 & 1.49 & 1.49 & 2.11 & 1.47 & 2.71 & 1.22 & 2.23 & 2.80 & 2.96 & 4.64 & 2.36 \\
0.44 & 0.57 & 0.59 & 0.67 & 0.87 & 0.89 & 0.76 & 0.60 & 0.66 & 0.67 & 0.67 & 0.95 & 0.67 & 1.22 & 0.55 & 1.01 & 1.26 & 1.33 & 2.08 & 1.06 \\
0.81 & 1.06 & 1.07 & 1.22 & 1.59 & 1.63 & 1.39 & 1.10 & 1.20 & 1.23 & 1.23 & 1.74 & 1.22 & 2.23 & 1.01 & 1.84 & 2.31 & 2.44 & 3.82 & 1.95 \\
1.02 & 1.33 & 1.34 & 1.53 & 2.00 & 2.05 & 1.74 & 1.38 & 1.51 & 1.54 & 1.54 & 2.18 & 1.53 & 2.80 & 1.26 & 2.31 & 2.90 & 3.06 & 4.80 & 2.44 \\
1.08 & 1.42 & 1.42 & 1.61 & 2.11 & 2.17 & 1.83 & 1.45 & 1.59 & 1.63 & 1.62 & 2.30 & 1.61 & 2.96 & 1.33 & 2.44 & 3.06 & 3.25 & 5.10 & 2.58 \\
1.69 & 2.22 & 2.22 & 2.52 & 3.31 & 3.4 & 2.87 & 2.27 & 2.49 & 2.55 & 2.54 & 3.61 & 2.52 & 4.64 & 2.08 & 3.82 & 4.80 & 5.10 & 7.99 & 4.05 \\
0.86 & 1.12 & 1.13 & 1.28 & 1.68 & 1.73 & 1.46 & 1.16 & 1.27 & 1.30 & 1.30 & 1.84 & 1.28 & 2.36 & 1.06 & 1.95 & 2.44 & 2.58 & 4.05 & 2.06
\end{pmatrix}$$

Again, the fuzzy variance-covariance are derived directly from fuzzy numbers, which is different from the probability theory where variance and covariance are derived from a great deal of historical data. Given the fuzzy mean and variance and co-variance values, we understand this fuzzy portfolio selection is a hard decision problem due to at least two reasons. First, fuzzy portfolio selection should take into consideration both the individual security risks (positive variance) and the system risks (positive correlation). Second, there exist several possible non-dominated securities. For example, both the first and second security can be selected because the first one has lower risk and return while the second one has both higher risk and return. This analysis reveals that fuzzy portfolio selection accommodates utility theory based portfolio selection problem.[24]

The upper bounds of x_i are given by, Let upper bounds of x_i be $\alpha_j = 0.4(j = 1, \cdots, 20)$, and $\beta = 0.05$, $\tilde{V} = (0.01,0.02,0.04,0.05)$, and then plug into the model (FMVSF). Solving this model using Matlab software, results were generated in 20 s giving the solutions are given in Table 13.2.

From Table 13.2, the model yields two findings. First, the investor knows that there is a tradeoff between risk and reward: To obtain greater expected fuzzy returns on investments, one must be willing to take on greater risk reflected in the parameter w. The best portfolio that the investor yields depends on his own tolerance for risk reflected in the parameter w. Second, when the risk increases, the investor can increase the number of securities he invests in to benefit from the diversification effect. Such conclusions are consistent with existing work.[25] Another very interesting finding is regarding the change of the investor's strategy. These involve two trends. First, when the investor's risk tolerance is small with the value being from 0.64 to unity, he prefers to select securities with lower risk and earn limited returns. Table 13.2 indicates the first security with fuzzy variance and mean being 0.36 and 13.83 and the fifth security with fuzzy variance and mean being 1.38 and 20.33 are preferred by the investor. When the investor's risk tolerance is large with the value

Table 13.2 Possibilistic efficient portfolios

w (risk) %	0.64	0.68	0.72	0.8	0.9	1	1.8	2.2
Expected return %	17.4	17.68	17.95	18.47	19.08	19.66	23.12	24.44
x_1	0.379	0.336	0.294	0.214	0.139	0.071	0	0
x_2	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
x_3	0	0	0	0	0	0	0	0
x_4	0	0	0	0	0	0	0	0
x_5	0.221	0.264	0.306	0.386	0.4	0.4	0	0
x_6	0	0	0	0	0	0	0	0
x_7	0	0	0	0	0	0	0	0
x_8	0	0	0	0	0	0	0	0
x_9	0	0	0	0	0	0	0	0
x_{10}	0	0	0	0	0	0	0	0
x_{11}	0	0	0	0	0	0	0	0
x_{12}	0	0	0	0	0	0	0	0
x_{13}	0	0	0	0	0	0	0	0
x_{14}	0	0	0	0	0	0	0.4	0.4
x_{15}	0	0	0	0	0	0	0	0
x_{16}	0	0	0	0	0.061	0.129	0.133	0.036
x_{17}	0	0	0	0	0	0	0	0
x_{18}	0	0	0	0	0	0	0	0
x_{19}	0	0	0	0	0	0	0.067	0.164
x_{20}	0	0	0	0	0	0	0	0

being from 1.8 to 2.2, he prefers to select securities with higher risk and earn more returns. Table 13.2 indicates the 14th security with fuzzy variance and mean being 2.71 and 13.67 and the 19th security with fuzzy variance and mean being 7.99 and 36 are preferred by the investor. Second, when the investor's risk tolerance increases, if a security has lower risk and return and is preferred, the proportion invested in this security will become less and less. For example, from Table 13.2 we can see that when the investor's risk tolerance is small with the value increased from 0.64 to unity, the proportion he holds the first security decreases from 0.379 to 0.071.

Conclusions

This chapter presented portfolio Selection under fuzzy and stochastic uncertainty as important financial risk management tools. Examples are shown by demonstrating implementation of the possibilistic mean variance safety-first portfolio selection model. Using this possibilistic mean variance safety-first portfolio selection model, fuzzy variance and co-variance are derived directly from fuzzy numbers, which is different from the probability theory where variance and co-variance are derived from a great deal

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Chapter 14
Business Scorecard Analysis to Measure Enterprise Risk Performance

Business scorecards are one of a number of quantitative tools available to support risk planning.[1] Olhager and Wikner[2] reviewed a number of production planning and control tools, where scorecards are deemed as the most successful approach in production planning and control performance measurement. Various forms of scorecards, e.g., company-configured scorecards and/or strategic scorecards, have been suggested to build into the business decision support system or expert system in order to monitor the performance of the enterprise in the strategic decision analysis.[3] This chapter demonstrates the value of small business scorecards with a case from a bank operation.

While risk needs to be managed, taking risks is fundamental to doing business. Profit by necessity requires accepting some risk.[4] ERM provides tools to rationally manage these risks. Scorecards have been successfully associated with risk management at Mobil, Chrysler, the US Army, and numerous other organizations.[5]

Enterprise risk management (ERM) provides the methods and processes used by business institutions to manage all risks and seize opportunities to achieve their objectives. ERM began with a focus on financial risk, but has expended its focus to accounting as well as all aspects of organizational operations in the past decade. Enterprise risk can include a variety of factors with potential impact on an organizations activities, processes, and resources. External factors can result from economic change, financial market developments, and dangers arising in political, legal, technological, and demographic environments. Most of these are beyond the control of a given organization, although organizations can prepare and protect themselves in time-honored ways. Internal risks include human error, fraud, systems failure, disrupted production, and other risks. Often systems are assumed to be in place to detect and control risk, but inaccurate numbers are generated for various reasons.[6]

ERM brings a systemic approach to risk management. This systemic approach provides more systematic and complete coverage of risks (far beyond financial risk, for instance). ERM provides a framework to define risk responsibilities, and a need to monitor and measure these risks. That's where business scorecards provide a natural fit – measurement of risks that are key to the organization.

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ERM and Balanced Scorecards

Beasley et al.[7] argued that business scorecards broaden the perspective of enterprise risk management. While many firms focus on Sarbanes-Oxley compliance, there is a need to consider strategic, market, and reputation risks as well. Balanced scorecards explicitly link risk management to strategic performance. To demonstrate this, Beasley et al. provided an example balanced scorecard for supply chain management, outlined in Table 14.1.

Other examples of business scorecard use have been presented as well, as tools providing measurement on a broader, strategic perspective. For instance, business scorecards have been applied to internal auditing in accounting[8] and to mental health governance.[9] Janssen et al.[10] applied a system dynamics model to the marketing of

Table 14.1 Supply chain management balanced scorecard

Measure	Goals	Measures
Learning and growth for employees To achieve our vision, how will we sustain our ability to change and improve?	Increase employee ownership over process Improve information flows across supply chain stages Increase employee identification of potential supply chain disruptions *Risk-related goals:* Increase employee awareness of supply chain risks Increase supplier accountabilities for disruptions Increase employee awareness of integration of supply chain and other enterprise risks	Employee survey scores Changes in information reports, frequencies across supply chain partners Comparison of actual disruptions with reports about drivers of potential disruptions Number of employees attending risk management training Supplier contract provisions addressing risk management accountability & penalties Number of departments participating in supply chain risk identification & assessment workshops
Internal business processes To satisfy our stakeholders and customers, where must we excel in our business processes?	Reduce waste generated across the supply chain Shorten time from start to finish Achieve unit cost reductions *Risk-related goals:* Reduce probability and impact of threats to supply chain processes Identify specific tolerances for key supply chain processes Reduce number of exchanges of supply chain risks to other enterprise processes	Pounds of scrap Time from raw material purchase to product/service delivery to customer Unit costs per product/service delivered, % of target costs achieved Number of employees attending risk management training Number of process variances exceeding specified acceptable risk tolerances Extent of risks realized in other functions from supply chain process risk drivers

Table 14.1 (continued)

Measure	Goals	Measures
Customer satisfaction To achieve our vision, how should we appear to our customers?	Improve product/service quality Improve timeliness of product/service delivery	Number of customer contact points Time from customer order to delivery Customer scores of value Number of customers retained Extent of negative coverage in business press of quality Customer scores of value
	Improve customer perception of value	Number of completed customer surveys about delivery comparisons to other providers
	Risk-related goals: Reduce customer defections Monitor threats to product/service reputation Increase customer feedback	
Financial performance To succeed financially, how should we appear to our stakeholders?	Higher profit margins Improved cash flows Revenue growth	Profit margin by supply chain partner Net cash generated over supply chain
	Risk-related goals: Reduce threats from price competition Reduce cost overruns Reduce costs outside the supply chain from supply chain processes	Increase in number of customers & sales per customer; % annual return on supply chain assets Number of customer defections due to price Surcharges paid, holding costs incurred, overtime charges applied Warranty claims incurred, legal costs paid, sales returns processed

Developed from Beasley et al. (2006).

natural gas vehicles, considering the perspective of 16 stakeholders ranging across automobile manufacturers and customers to the natural gas industry and government. Policy options were compared, using business scorecards with the following strategic categories of analysis:

- Natural gas vehicle subsidies
- Fueling station subsidies
- Compressed natural gas tax reductions
- Natural gas vehicle advertising effectiveness.

Business scorecards provided a systematic focus on strategic issues, allowing the analysts to examine the nonlinear responses of policy options as modeled with system dynamics. Five indicators were proposed to measure progress of market penetration:

1. Ratio of natural gas vehicles per compress natural gas fueling stations
2. Type coverages (how many different natural gas vehicle types were available)
3. Natural gas vehicle investment pay-back time
4. Sales per type
5. Subsidies par automobile

Small Business Scorecard Analysis

This section discusses computational results on various scorecard performances currently being used in a large bank to evaluate loans to small businesses. This bank uses various ERM performance measures to validate a small business scorecard (SBB). Because scorecards have a tendency to deteriorate over time, it is appropriate to examine how well they are performing and to examine any possible changes in the scoring population. A number of statistics and analyses will be employed to determine if the scorecard is still effective.

ERM Performance Measurement

Some performance measures for enterprise risk modeling are reviewed in this section. They are used to determine the relative effectiveness of the scorecards. More details are given in our work published elsewhere.[11] There are four measures reviewed: the Divergence, Kolmogorov-Smirnov (KS) Statistic, Lorenz Curve and the Population stability index. *Divergence* is calculated as the squared difference between the mean score of good and bad accounts divided by their average variance. The dispersion of the data about the means is captured by the variances in the denominator. The divergence will be lower if the variance is high. A high divergence value indicates the score is able to differentiate between good and bad accounts. Divergence is a relative measure and should be compared to other measures. The KS Statistic is the maximum difference between the cumulative percentage of goods and cumulative percentage of bads for the population rank-ordered according to its score. A high KS value shows it is very possible that good applicants can receive high scores and bad applicants receive low scores. The maximum possible K-S statistic is unity. *Lorenz Curve* is the graph that depicts the power of a model capturing bad accounts relative to the entire population. Usually, three curves are depicted: a piecewise curve representing the perfect model which captures all the bads in the lowest scores range of the model, the random line as a point of reference indicating no predictive ability, and the curve lying between these two capturing the discriminant power of the model under evaluation. *Population stability index* measures a change in score distributions by comparing the frequencies of the corresponding scorebands, i.e., it measures the difference between two populations. In practice, one can judge there is no real change between the populations if an index value is no larger than and a definite population change if index value is greater than 0.25. An index value between 0.10 and 0.25 indicates some shift.

Data

Data are collected from the bank's internal database. "Bad" accounts are defined into two types: "Bad 1" indicating Overlimit at month-end, and "Bad 2" referring to those with 35 days since last deposit at month-end. All non-bad accounts will be classified as "Good". We split the population according to Credit Limit: one for Credit Limit less than or equal to $500,000 and the other for Credit Limit between $50,000 and $100,000. Data are gathered from two time slots: observed time slot and validated time slot. Two sets (denoted as Set1 and Set2) are used in the validation. Observed time slots are from August 2002 to January 2003 for Set1 and from September 2001 to February 2002 for Set2 respectively. While this data is relative dated, the system demonstrated using this data is still in use, as the bank has found it stable, and they feel that there is a high cost in switching. Validated time slot are from February 2003 to June 2003 for Set1 and from March 2002 to July 2002 for Set2 respectively. All accounts are scored on the last business day of each month. All non-scored accounts will be excluded from the analyses.

Table 14.2 gives the bad rates summary by Line Size for both sets while Table 14.3 reports the score distribution for both sets, to include the Beacon score accounts. From Table 14.2, we can see that in both sets, although the number of Bad1 accounts is a bit less than that of Bad2 accounts, it is still a pretty balanced data. The bad rates by product line size are less than 10%. The bad rates decreased with respect to time by both product line and score band, as can be seen from both tables. For example, for accounts less than or equal to $50 million, we can see from the third row of Table 14.2 that the bad rate decreased from 9.46 and 2.80% in February 2002 to 8.46 and 1.85% in January 2003 respectively.

Table 14.2 Bad loan rates by loan size

	Bad loans 1 Jan 2003(set1)			Bad loans 2 Jan 2003(set1)		
Limit	*N*	No. of bad loans	Bad rate (%)	*N*	No. of bad loans	Bad rate (%)
≤$50 million	59,332	5,022	8.46	61,067	1,127	1.85
$50–$100 million	6,777	545	8.04	7,000	69	0.99
Total	66,109	5,567	8.42	68,067	1,196	1.76
	Bad loans 1 Feb 2002 (set2)			Bad loans 2 Feb 2002 (set2)		
	N	No. of bad loans	Bad rate (%)	*N*	No. of bad loans	Bad rate (%)
≤$50 million	61,183	5,790	9.46	63,981	1,791	2.80
$50–$100 million	6,915	637	9.21	7,210	88	1.22
Total	68,098	6,427	9.44	71,191	1,879	2.64

Note: Bad 1: overlimit; Bad 2: 35+ days since last deposit and overlimit.

Table 14.3 Score statistical summary

Score band	Bad loans 1 Jan 2003(set1)			Bad loans 2 Jan 2003(set1)		
	N	Bad	Bad rate (%)	N	Bad	Bad rate (%)
0	1,210	125	10.33	1,263	27	2.14
1–500	152	58	38.16	197	27	13.70
501–550	418	117	27.99	508	49	9.65
551–600	1,438	350	24.34	1,593	109	6.84
601–650	4,514	858	19.01	4,841	194	4.01
651–700	11,080	1,494	13.48	11,599	321	2.77
701–750	18,328	1,540	8.40	18,799	312	1.66
751–800	21,083	888	4.20	21,356	149	0.70
≥800	9,096	262	2.88	9,174	35	0.38
Beacon	12,813	769	6.00	13,054	328	2.51
Total	80,132	6,461	8.06	82,384	1,551	1.88
Score band	Bad loans 1 Feb 2002(set2)			Bad loans 2 Feb 2002(set2)		
	N	Bad	N	Bad	N	Bad
0	1,840	215	1,840	215	1,840	215
1–500	231	92	231	92	231	92
501–550	646	189	646	189	646	189
551–600	2,106	533	2,106	533	2,106	533
601–650	5,348	1,078	5,348	1,078	5,348	1,078
651–700	11,624	1,641	11,624	1,641	11,624	1,641
701–750	18,392	1,647	18,392	1,647	18,392	1,647
751–800	20,951	969	20,951	969	20,951	969
≥800	8,800	278	8,800	278	8,800	278
Beacon	17,339	1,349	17,339	1,349	17,339	1,349
Total	87,277	7,991	87,277	7,991	87,277	7,991

Results and Discussion

Computation is done in two steps: (1) Score Distribution and (2) Performance Validation. The first step examines the evidence of a score shift. This population consists of the 4 types of business line of credit (BLOC) products. The second step measures how well models can predict the bad accounts within a 5-month period. This population only contains one type of BLOC account.

Score Distribution

Figure 14.1 depicts the population stability indices values from January 2001 to June 2003. The values of indices for the $50,000 and $100,000 segments show a steady increase with respect time. The score distribution of the data set is becoming more unlike the most current population as time spans. Yet, the indices still remain below the benchmark of 0.25 that would indicate a significant shift in the score population.

The upward trend is due to two factors: time on books of the accounts and credit balance. A book of the account refers to a record in which commercial accounts are

Fig. 14.1 Population stability indices (January 02–June 03)

recorded. First, as the portfolio ages, more accounts will be assigned lower values (i.e. less risky) by the variable time on books of the accounts, thus contributing to a shift in the overall score. Second, more and more accounts do not have a credit balance as time goes. As a result, more accounts will receive higher scores to indicate riskier behavior.

The shifted score distribution indicates that the population used to develop the model is different from the most recent population. As a result, the weights that had been assigned to each characteristic value might not be the ones most suitable for the current population. Therefore, we have to conduct the following performance validation computation.

Performance

To compare the discriminate power of the SBB scorecard with the credit bureau scorecard model, we depict the Lorenz Curve for both "Bad 1" and "Bad 2" accounts in Figs. 14.2 and 14.3. From both Figs. 14.2 and 14.3, we can see that the SBB model still provides an effective means of discriminating the "good" from "bad" accounts and that the SBB scorecard captures bad accounts much more quickly than the Beacon score. Based on the "Bad 1" accounts in January 2003, SBS capture 58% of bad accounts, and outperforms the Beacon value of 42%. One of the reason for Beacon model being bad in capturing bad accounts is that the credit risk of one of the owners may not necessarily be indicative of the credit risk of the business. Instead, a Credit Bureau scorecard based on the business may be more suitable.

Table 14.4 reports various performance statistic values for both "Bad 1" and "Bad 2" accounts. Two main patterns are found. First, the Divergence and K-S score values produce consistent results as Lorenz Curve did. For both "Bad 1" and "Bad 2", the SBB scorecard performs better than the bureau score in predicting a bad account. Second, SBS based on both bad accounts possibly experience performance deterioration. Table 14.4 shows that all performance statistic based on the January 2003 data are worse than those of the February 2002 period. For example, the "Bad 1" scorecard generates K-S statistic scores of 78 and 136, for January

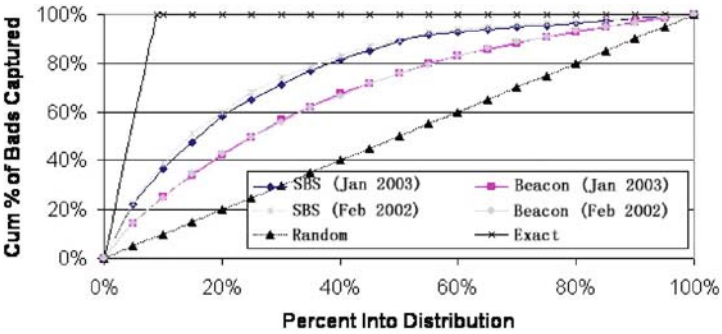

Fig. 14.2 Lorenz curve for “Bad 1” accounts

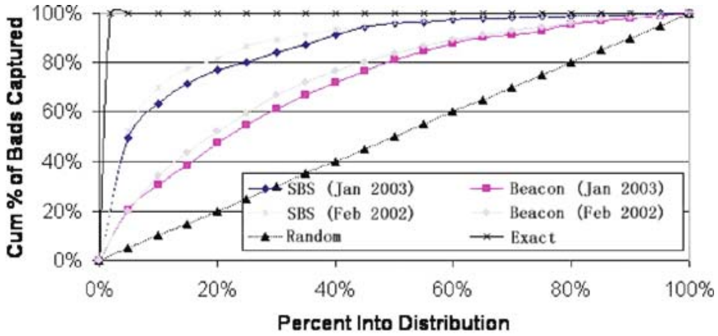

Fig. 14.3 Lorenz curve for “Bad 2” accounts

Table 14.4 Performance statistics for both “Bad 1” and “Bad 2” accounts

Statistic	SBS (Jan 2003)	Beacon (Jan 2003)	SBS (Feb 2002)	Beacon (Feb 2002)	SBS (Jan 2003)	Beacon (Jan 2003)	SBS (Feb 2002)	Beacon (Feb 2002)
No. of good	60,542	60,542	61,671	61,671	66,871	66,871	69,312	69,312
Mean good	108.89	738.71	127.3	734.67	137.4	734.28	171.81	729.23
Std. good	172.74	60.18	203.26	63.53	221.22	62.78	284.21	66.66
	“Bad 1” accounts				“Bad 2” accounts			
No. of accounts	5,567	5,567	6,427	6,427	1,196	1,196	1,879	1,879
Mean score	344.9	693.13	439.63	685.79	699.82	678.03	995.65	663.2
Std. Dev.	321.53	69.45	387.24	73.27	570.77	75.42	756.34	76.08
Bad rate (%)	8.42	8.42	9.44	9.44	1.76	1.76	2.64	2.64
Divergence	0.836	0.492	1.02	0.508	1.688	0.657	2.079	0.852
K-S	78	726	136	716	233	726	394	707

Table 14.5 Performance statistics for both credit lines

	Credit line	Limit <= $50 million				Limit $50–$100 million			
	Statistic	SBS (Jan 2003)	Beacon (Jan 2003)	SBS (Feb 2002)	Beacon (Feb 2002)	SBS (Jan 2003)	Beacon (Jan 2003)	SBS (Feb 2002)	Beacon (Feb 2002)
Good	No of accounts	47,682	47,682	48,539	48,539	6,232	6,232	6,278	6,278
	Mean	116.12	737.77	138.80	733.12	115.13	752.18	125.52	752.64
	Std.	177.34	59.12	213.62	62.52	161.93	54.61	174.07	55.86
Bad	No. of accounts	4,393	4,393	5,226	5,226	545	545	637	637
	Mean score	347.40	695.10	461.06	686.03	345.82	715.80	398.05	711.95
	Std. Dev.	314.69	65.68	391.94	71.87	285.01	68.35	310.59	62.28
Performance	Bad rate (%)	8.44	8.44	9.72	9.72	8.04	8.04	9.21	9.21
	Divergence	0.820	0.466	1.042	0.489	0.991	0.346	1.172	0.473
	K-S	78	726	136	717	125	735	162	742

2003 and February 2003 respectively. The "Bad 2" scorecard generates K-S statistic scores of 233 and 394 for both periods.

Table 14.5 gives performance statistic values for both credit lines. i.e., accounts with Credit Limit less than or equal to $50 million and between $50 million and $100 million. This table shows a comparison between accounts with a limit of $50 million and those with limits between $50 million and $100 million. Two main patterns are found. First, the Small Business Scorecards perform well on both, and outperform the Beacon score on both segments. Second, both scorecards, especially the Small Business Scorecard, perform better on "Bad 2" accounts. The main reason is that "Bad 2" definition specifies a more severe degree of delinquency and the difference between the good and bad accounts is more distinct.

Conclusions

Business scorecard analysis provides a means to measure multiple strategic perspectives. The basic principle is to select four diverse areas of strategic importance, and within each, to identify concrete measures that managers can use to gauge organizational performance on multiple scales. This allows consideration of multiple perspectives or stakeholders. Examples given included supply chain risk analysis, and policy analysis of natural gas vehicle adoption. This chapter focused on the example of a small bank credit situation. Computation results indicate there is evidence of a shifting score distribution utilized by the scorecard. However, the scorecard still provides an effective means to predict "bad" accounts.

Business scorecards have been widely applied in general, but not specifically to enterprise risk management. This chapter demonstrates how the business scorecard can be applied to evaluate the risk management posture of a particular organization. The demonstration specifically is for a bank, but other organizations could measure appropriate risk elements for their circumstances. Business scorecards offer the flexibility to include any type of measure key to production planning and operations of any type of organization.

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