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Risk Analysis and Risk Management: An Historical Perspective

Vincent T. Covello[1] and Jeryl Mumpower[2]

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This paper reviews the history of risk analysis and risk management, giving special emphasis to the neglected period prior to the 20th century. The overall objective of the paper is to: (1) dampen the prevailing tendency to view present-day concerns about risk in an ahistorical context; (2) shed light on the intellectual antecedents of current thinking about risk; (3) clarify how contemporary ideas about risk analysis and societal risk management differ significantly from the past; and (4) provide a basis for anticipating future directions in risk analysis and management.

KEY WORDS: History of risk analysis; probability theory; risk analysis; risk management.

1. INTRODUCTION

In the Tigris-Euphrates valley about 3200 B.C. there lived a group called the Asipu. One of their primary functions was to serve as consultants for risky, uncertain, or difficult decisions. If a decision needed to be made concerning a forthcoming risky venture, a proposed marriage arrangement, or a suitable building site, one could consult with a member of the Asipu. The Asipu would identify the important dimensions of the problem, identify alternative actions, and collect data on the likely outcomes (e.g., profit or loss, success or failure) of each alternative. The best available data from their perspective were signs from the gods, which the priest-like Asipu were especially qualified to interpret. The Asipu would then create a ledger with a space for each alternative. If the signs were favorable, they would enter a plus in the space; if not, they would enter a minus. After the analysis was completed, the Asipu would recommend the most favorable alternative. The last step was to issue a final report to the client, etched upon a clay tablet.[1]

According to Grier,[2,3] the practices of the Asipu mark the first recorded instance of a simplified form of risk analysis. The similarities between the practices and procedures of modern risk analysts and those of their Babylonian forebears underscore the point that people have been dealing with problems of risk for a long time, often in a sophisticated and quantitative way.

This paper reviews the history of risk analysis and risk management giving special emphasis to the neglected period prior to the 20th century. It is hoped that this review will accomplish the following:

- Dampen the prevailing tendency to view present-day concerns about risk in an ahistorical context.
- Shed light on the intellectual antecedents of current thinking about risk.
- Clarify how contemporary ideas about risk analysis and societal risk management differ significantly from the past.

[1] Division of Policy Research and Analysis, National Science Foundation, 1800 G St., NW, Washington, D.C. 20550.
[2] Graduate School of Public Affairs, State University of New York at Albany, 135 Western Ave., Albany, New York 12222.

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- Provide a basis for anticipating future directions in risk analysis and management.

This paper is divided into five major sections. The first discusses the early antecedents of quantitative risk analysis, with an emphasis on the development of probability theory. It would be difficult, if not impossible, to separate contemporary risk analysis from mathematical notions of probability. Yet our review indicates that probability, expressed quantitatively, is a relatively recent idea. Although precursors of contemporary risk analysis can be traced as far back as early Mesopotamia, it was not until the emergence of probability theory in the 17th century that the intellectual tools for quantitative risk analysis became available.

The second section discusses the development of scientific methods for establishing or demonstrating causal links or connections between adverse health effects and different types of hazardous activities. Such methods are as essential to modern risk analysis as is probability theory. Despite their importance, however, progress in developing such methods was exceedingly slow. Several possible explanations are considered.

The third section focuses on mechanisms for coping with risks and discusses the principal antecedents of contemporary societal risk management strategies. Four major strategies are discussed: insurance, common law, government intervention, and private sector self-regulation. In each instance, examples are cited that closely resemble but considerably predate modern practice.

The fourth section discusses nine changes between the past and the present which we consider to be among the most significant for risk analysis and risk management.

The final section attempts to anticipate some likely future directions in risk analysis and risk management.

2. QUANTITATIVE RISK ANALYSIS AND PROBABILITY

Unlike modern risk analysts, who express their results in terms of mathematical probabilities and confidence intervals, the Asipu of ancient Babylonia expressed their results with certainty, confidence, and authority. Since the Asipu were empowered to read the signs of the gods, probability played no part in their analyses. Faulty predictions, as in other forms of divination, were readily rationalized according to initial premises and posed no threat to the system.[4,5] The search for the origins of modern quantitative risk analysis must, therefore, look elsewhere.

An important thread leading to modern quantitative risk analysis can be traced to early religious ideas concerning the probability of an afterlife. This should hardly be surprising, considering the salience and seriousness of the risks involved (at least for true believers). Beginning with Plato's *Phaedo* in the 4th century B.C., numerous treatises have been written discussing the risks to one's soul in the afterlife based on how one conducts oneself in the here and now.

One of the most sophisticated analyses of this issue was carried out by Arnobius the Elder, who lived in the 4th century A.D. in North Africa. Arnobius was a major figure in a pagan church that was competing at the time with the fledgling Christian church. Members of Arnobius' church, who maintained a temple to Venus complete with virgin sacrifices and temple prostitution, led a decadent life in comparison to the austere Christians. Arnobius taunted the Christians for their lives of pointless self abnegation; but, after a revelatory vision, renounced his previous beliefs and attempted to convert to Christianity. The bishop of the Christian church, suspicious of Arnobius' motives and the sincerity of his conversion, refused him the rite of baptism. In an effort to demonstrate the authenticity of his conversion, Arnobius authored an eight-volume monograph entitled *Against the Pagans*. In this work, Arnobius made a number of arguments for Christianity, one of which is particularly relevant to the history of probabilistic risk analysis. After thoroughly discussing the risks and uncertainties associated with decisions affecting one's soul, Arnobius proposed a 2×2 matrix. There are, he argued, two alternatives: "accept Christianity" or "remain a pagan." There are also, he argued, two possible, but uncertain, state of affairs: "God exists" or "God does not exist." If God does not exist, there is no difference between the two alternatives (with the minor exception that Christians may unnecessarily forgo some of the pleasures of the flesh enjoyed by pagans). If God exists, however, being a Christian is far better for one's soul than being a pagan.

According to Grier,[3] Arnobius' argument marks the first recorded appearance of the *dominance principle*, a useful heuristic for making decisions under conditions of risk and uncertainty. Through his student Lactinius, and later St. Jerome and St. Augustine, this argument entered the mainstream of Christian theology and intellectual thought. When Pascal introduced probability theory in 1657, one of his first applications was to extend Arnobius' matrix. Given the probability distribution for God's existence, Pascal concluded that the expected value of being a Christian outweighed the expected value of atheism.

In addition to Pascal's seminal work,[(6)] the late 17th and 18th centuries witnessed a remarkable spurt of intellectual activity related to probability theory.[(7)] In 1692, John Arbuthnot argued that the probabilities of different potential causes of an event could be calculated. In 1693, Halley proposed improved life expectancy tables. In 1728, Hutchinson examined the tradeoff between probability and utility in risky-choice situations. In the early 18th century, Cramer and Bernoulli proposed solutions to the St. Petersburg paradox. Then, in 1792, LaPlace developed a true prototype of modern quantitative risk assessment—an analysis of the probability of death with and without smallpox vaccination.[(8)]

What caused this unprecedented surge of activity in the mathematical theory of probability? For decades, historians of science have grappled with this question. In 1865, Isaac Todhunter wrote a work entitled *A History of the Mathematical Theory of Probability From the Time of Pascal to that of Laplace*.[3] Only six of the 618 pages in the text deal with Pascal's predecessors. The dearth of material was not a simple omission by Todhunter. Nor was it due to a lack of historical diligence and scholarship. Instead, it appears that formal quantitative concepts of probability were not understood to any substantial degree before the time of Pascal. Prior to Pascal, there was virtually no history of probability theory. Yet after LaPlace, the laws of probability were so well understood that a bibliography of early work on the subject would cover several hundred pages.

How can this be? What makes the situation even more difficult to understand is that man's fascination with games of chance appears to be nearly as old as man himself. As David[(9)] has shown, games of chance may have been one of the first inventions of primitive man. In sites throughout the ancient world, archeologists have uncovered large numbers of tali, a predecessor of modern dice shaped from the "knucklebone" or heel of deer, horses, oxen, or sheep. A talus is so formed that when it is thrown on a level surface, it can come to rest in only four ways. Well polished and often engraved examples of tali are regularly found in ancient Egyptian, Sumerian, and Assyrian sites. Tomb illustrations and scoring boards make it virtually certain that these were used for gaming. During the Roman era, Marcus Aurelius was so obsessed with throwing dice that he was regularly accompanied by his own master of games. It would seem to follow that the mathematical calculation of relative frequencies and averages should be as old as the rolling of such ancient devices. Yet mathematical theories of relative frequency, betting, randomness, and probability only appear 1500 years later in the work of Pascal, Bernoulli, and others.

Several tentative explanations have been offered, none of which is entirely satisfactory.[(10,11)] First, it has been argued that mathematical probability theory developed in response to specific economic needs. According to this argument, the rapid development of probability theory in the 17th and 18th centuries can, in part, be traced to the rise of capitalism. This, in turn, can be related to the desire of the new mercantile class for improved methods of business calculation and for greater economic security in the form of insurance. But early probability theorists were generally not involved in commerce, nor was their work readily applicable to business.

A second argument, related to the first, argues that the development of mathematical probability theory was related to the growth of firms dealing in life annuities. This argument falters, however, when one considers that by the third century A.D., the selling of annuities was already a common practice in Rome.

A third argument is that prior to the 17th century mathematics was not sufficiently rich in concepts and ideas to generate a theory of probability. According to this argument, the mathematics of probability became possible when limit theorems became possible. This argument falters when one considers that the concept of probability requires little besides simple arithmetic. In response, supporters of this argument claim that prior to the 17th century the arithmetic symbolism needed for easy addition and multiplication did not exist, and that such a symbolism is a prerequisite for probability.

A fourth argument is that the conditions leading to the emergence of a mathematical theory of probability are the same as those leading to the emergence of modern science in the 16th and 17th centuries.

[3]Reprinted by G. E. Stechert and Company, New York, 1931.

While it has long been commonly accepted that theoretical and methodological developments during this period, particularly in England and France, constituted a scientific revolution, it is not at all clear why or how this came about. Numerous theories have been proposed, from the theories of Marx,[12] concerning changes in the economic means of production; to Merton's theory[13] concerning the link between religion, the Protestant reformation, and scientific developments; and to relatively recent theories which link the emergence of modern science to a complex chain of scientific, technological, political, economic, religious, institutional, and ideological changes.[14-16]

A fifth argument, offered by Grier,[3] is that the preconditions for the emergence of probability theory were established approximately a century and a half before Pascal, largely because of a change in attitude of the Catholic Church. Grier notes that in the 14th century the Catholic Church experienced a serious cash flow situation. On the one hand, money was needed to pay the massive debts arising from the Crusades—which had been extraordinarily, almost ruinously, expensive. On the other, money was also needed to pay for new church construction in response to growing population pressure. Money was, however, in short supply, since the Church prohibited usury. In order to reconsider the matter, the Church formed an advisory panel of scholars. At the same time, the financial community hired John Ecks, a university professor, to argue on their behalf. In 1518, the Laettian Council adopted a scholars' report that redefined usury in such a way that interest was permitted as long as there was risk incurred on the part of the lender. Although this definition was rescinded in 1586 (and the Church did not sanction interest again until 1830), Grier argues that the 68 years of sin-free interest rates were enough to stir up intellectual thought about probability. The real change, he argues, was not in law or morality, but in making risk a legitimate topic of discussion. He believes that much of the intellectual thinking about probability in the 17th and 18th centuries had its roots in the discussions of risk in the Church's debates over interest rates.

Whatever the true explanation or explanations, it did not take long for the new theories of probability to be applied to the human condition. Within 100 years of Pascal's discovery, several individuals were using mathematical theories of probability to examine life expectancies. Prior to this work the only life expectancy tables of note were those developed by the Roman Domitius Ulpianus in 230 A.D. Similar efforts were not made until Graunt published his life expectancy tables in 1662. In explaining this large gap, it appears that philosophical objections played a major role. As David[9] points out, there "...seems to have been a taboo on speculations with regard to health, philosophers implying that to count the sick or even the number of boys born was impious in that it probed the inscrutable purpose of God."

Graunt's work represents the first recorded attempt to calculate empirical probabilities on any scale. The raw data for his tables were parish records of births and deaths. In the conclusion of his work, Graunt[17] offers several remarks that might apply equally to the work of contemporary risk analysts:

> "It may be now asked, to what purpose tends all this laborious puzzling and groping?... I might answer; That there is much pleasure in deducing so many abstruse and unexpected inferences out of these poor despised Bills of Mortality; and in building upon that ground, which hath lain waste these eighty years. And there is pleasure in doing something new, though never so little, without pestering the World with voluminious Transcriptions. But, I answer more seriously,... that a clear knowledge of these particulars, and many more, whereat I have shot but at rovers, is necessary in order for good, certain, and easy Government, and even to balance Parties and factions both in Church and State. But whether the knowledge thereof be necessary to many, or fit for others, than the Sovereign, and his chief Ministers, I leave to consideration."

Not long after Graunt published his tables, Halley (better remembered for the comet that bears his name) published an article[18] containing mortality tables based on the records of births and deaths at various ages in the city of Breslau. Halley's probabilistic analysis of the data convincingly disproved popular theories about the effect of phases of the moon on health. His results, as will be discussed later, provided the foundation or one of the pillars of modern societal risk management—life insurance.

One of the earliest systematic attempts to apply probability theory to a risk problem was by Von Bortkiewicz in the 19th century.[19] Von Bortkiewicz built on previous work done by Poisson to calculate theoretically the annual number of Prussian soldiers dying from kicks by horses. He studied records covering a span of 10 years to determine whether an observed rash of kicking accidents represented a random event or a change in circumstance requiring action (e.g., a rise in carelessness by soldiers or an increase in the number of wild horses). The analysis indicated that the occurrences he observed were indeed random events and that no special disciplinary actions were required.

3. METHODS FOR ESTABLISHING CAUSALITY

Modern risk analysis has its twin roots in mathematical theories of probability, and in scientific methods for identifying causal links between adverse health effects and different types of hazardous activities. Researchers throughout history have relied principally on methods of observation to unravel these links. The most basic form of such methods, and the most universally practiced, is experience based on trial and error. Since primitive times, human beings have upon occasion simply undertaken a new activity of interest (e.g., tasted a strange plant or launched a new boat) and have observed the adverse effects, if any. A slight variant of this method has been to distance oneself and conduct the experiment on a surrogate (e.g. feed new foods to animals). On a more complex level, researchers have used both indirect observational methods, such as the burn tests developed by Pliny the Elder in first century A.D. Rome to detect food adulteration[20]; and epidemiological observational methods (i.e., methods that seek to establish associations or cause-effect relationships through the observation of adverse health effects in clusters of cases). Although the early researchers in this second tradition did not adherer to the rigorous scientific and statistical standards of modern epidemiological studies,[21,22] the historical record is replete with examples. The association between malaria and swamps, for example, was established in the 5th century B.C. even though the precise reason for the association remained obscure. In the book *Airs, Waters, and Places*, thought to have been written by Hippocrates in the 4th or 5th century B.C., an attempt was made to set forth a causal relationship between disease and the environment. As early as the 1st century B.C., the Greeks and Romans had observed the adverse effects of exposure to lead through various mediums.[23,24] For example, the Roman Vitruvious (cited in Ref. 25), wrote:

> "We can take example by the workers in lead who have complexions affected by pallor. For when, in casting, the lead receives the current of air, the fumes from it occupy the members of the body, and burning them thereon, rob the limbs of the virtues of the blood. Therefore it seems that water should not be brought in lead pipes if we desire to have it wholesome."

Unfortunately, the observations of the ancient Greeks and Romans were soon forgotten and work did not begin anew until the 16th, 17th, and 18th centuries. Among the many studies conducted during this period, the following stand out:

- A study by Agricola[26] linking adverse health effects to various mining and metallurgical practices.
- A study by Evelyn[27] linking smoke in London to various types of acute and chronic respiratory problems.
- A study by Ramazzini[28] indicating that nuns living in Appennine monasteries appeared to have higher frequencies of breast cancer (Ramazzini suggested that this might be due to their celibacy, an observation that is in accord with recent observations that nulliparous women may develop breast cancer more frequently than women who have had children—see Refs. 29 and 30).
- A study by Hill[31] linking the use of tobacco snuff with cancer of the nasal passage.
- A study by Sir Percival Pott[32] indicating that juvenile chimney sweeps in England were especially susceptible to scrotal cancer at puberty.
- A study by Ayrton-Paris[33] as well as by Hutchinson[34] indicating that occupational and medicinal exposures to arsenic can lead to cancer.
- A study by Chadwick[35] linking nutrition and sanitary conditions in English slums to various types of ailments.
- A study by Snow[36] linking cholera outbreaks to contaminated water pumps.
- Studies by Unna[37] and Dubreuilh[38] linking sunlight exposure with skin cancer.
- A study by Rehn[39] linking aromatic amines with bladder cancer.

Despite these studies, progress in establishing causal links between adverse health effects and different types of hazardous activities was exceedingly slow. It appears that at least two major obstacles impeded progress. The first was the paucity of scientific models of biological, chemical, and physical processes, especially prior to the 17th and 18th centuries. Related to this was the lack of instrumentation and the lack of rigorous observational and experimental techniques for collecting data and testing hypotheses. Shapiro (cited in Ref. 40) described two revolutionary intellectual developments affecting science (and law):

> "The first was the drive for systematic arrangements and presentation of existing knowledge into scientifically organized categories... The second... was the concern with degrees of certainty... or probability... By the end of the 17th century... traditional views... had been upset and new methods of determining truth and investigating the natural world had replaced those that had been accepted for centuries... there was a strong movement toward arranging both concepts and data into some rational ordering that could be easily communicated and fitted into the materials of other fields so that a universal knowledge might emerge."

Although often taken for granted in today's world, even basic medical knowledge is a relatively recent development. It is surprisingly easy to forget that it was not until the work of Pasteur in the late 19th century that scientists first began to comprehend adequately the concept of infection or the causal relationship between the environment and biological agents of infectious disease.

The second obstacle was the belief, rooted in ancient traditions, that most illnesses, injuries, misfortunes, and disasters could best be explained in social, religious, or magical terms (e.g., by the will of the gods, by some moral transgression, or by the malevolence of an unseen enemy). In 16th and 17th century Europe, witch hunting resulted in death by fire for an estimated half-million people, as the Church attempted to eradicate a perceived source of crop failures, disease, death, and other ill fortune.[41] In 1721, an influential critic of medical experimentation in Boston insisted that smallpox is "a judgment of God on the sins of the people" and that "to avert it is... an encroachment on the prerogatives of Jehovah, whose right it is to wound and smite."[42] For many such critics, the direct physical agent that caused the harm was of considerably less interest than the moral status of the victim. In the mid-19th century, for example, critics opposed to health reforms in the Lowell, Massachusetts textile factories (including a large number of influential physicians) blamed symptoms of disease among factory workers on the workers' "improvident" style of life.[43]

4. SOCIETAL RISK MANAGEMENT

In response to identified risks, individuals and groups have historically employed a number of techniques for reducing or mitigating adverse health effects. These include the following:

- Avoiding or eliminating the risk, such as prohibiting the use of a potentially dangerous object or substance.
- Regulating or modifying the activity to reduce the magnitude and/or frequency of adverse health effects, e.g., by constructing dams, levees, and seawalls.
- Reducing the vulnerability of exposed persons and property, e.g., by requiring the use of safety devices, by elevating buildings in floodplains, by immunizing the population, by implementing quarantine laws, or by establishing disaster warning systems.
- Developing and implementing post-event mitigation and recovery procedures, e.g., by establishing search and rescue teams, stockpiling food, providing first aid training, or providing fire extinguishing equipment and services.
- Instituting loss-reimbursement and loss-distribution schemes through such mechanisms as insurance systems or incentive pay schedules for high risk activities.

Although all of these techniques are still practiced, most of our current ideas about societal risk management are rooted in four basic strategies or mechanisms of control: insurance, common law, government intervention, and private sector self-regulation. Each is discussed below.

4.1. Insurance

Insurance is one of the oldest strategies for coping with risks.[44] Its origins can be traced to early attempts at setting interest rates, which first arose in Mesopotamia. Records of interest rates in that area predate 3000 B.C. The practice appears to have originated when successful farmers loaned a portion of their excess production in exchange for a share of the return. At first, loaned goods were returned in kind along with the interest charge, but subsequently barley and then silver became the media of exchange. Differences in interest rates quickly emerged, ranging from zero for personal loans among friends to 33% for presumably much riskier agricultural loans. Inasmuch as interest rates reflected the perceived riskiness of the loan, they represented one of the earliest attempts to quantify and manage risk.[3]

The connection between interest rates and insurance can be traced to ancient Babylon. A natural trade center, Babylonia occupied a place as the center of the world economy in the pre-Greek period. Imports and exports flowed through Babylonia to and from both the east and the west. Traders faced numerous hazards in the form of bandits, pirates, fires, storms, and other assorted misfortunes. Loans extended on cargo in transit ordinarily included risk premiums as large as 200% in excess of interest. Because the borrower often posted all his property and sometimes his family as collateral, misfortune could prove truly catastrophic. Under these conditions trade declined, until insurance emerged as a more effective risk management technique. The Code of Hammurabi, issued about 1950 B.C.,[45] established several doctrines of risk management and laid the basis for the institutionalization of insurance. It formalized the concept of *bottomry*, which formed the basis for maritime contracts on vessels and cargoes. These bottomry contracts contained three elements: (1) the loan on the vessel, cargo, or freight; (2) an interest rate; and (3) a risk premium for the chance of loss and consequent cancellation of the debt. Bottomry quickly spread throughout the ancient world and represents one of the oldest attempts to cope with risk in a systematic, quantitative fashion.

By 750 B.C., bottomry was highly developed, particularly in Greece. At that time almost all voyages were covered by bottomry contracts, with 10–25% risk premiums, depending upon the perceived riskiness of the venture. (It is interesting to note here the etymology of the English word "risk". According to the *Unabridged Random House Dictionary*, the word risk comes to us through the French, Italian, and Latin, originating from the Greek word *rhiza*, in reference to the hazards of sailing around a cliff.) During this same period, the concept of *general average*, which called for all parties to share proportionately in any loss suffered during a venture, was also developed. This device established a mechanism for risk sharing, and provided a foundation for the first insurance exchange that developed and flourished in Athens.

With the decline of Greek civilization the Western development of insurance institutions also declined, although the Romans continued the practice of bottomry. The Romans did institute a rudimentary form of life and health insurance, however, in the form of *collegia*. Although burial societies had existed in Greece, the collegia of the Romans were much more highly developed. Members made regular contributions, a fund was maintained, and burial and last expenses were paid by the collegia.

Insurance almost disappeared in the West after the fall of the Roman Empire. Although the European guilds provided some protection to their members against various calamities, it was not insurance per se. Marine insurance reappeared in the Italian port cities, perhaps as early as 1000 A.D. and certainly by the 12th–14th centuries, becoming progressively more widespread and better developed. The Hanseatic League and Lombards, in particular, developed detailed sets of regulations pertaining to marine insurance, as evidenced by the Laws of Wisby (1300), the Ordinance of Barcelona (1435), and the Guidon de la Mer (circa 1600). In 1688, Lloyd's was established and London emerged as the nucleus of the global marine insurance market, later extending into other areas of insurance.

From the 17th century on, the insurance industry flourished in England. Fire insurance, for example, developed in London in response to the Great Fire of 1666 and quickly achieved great success. Life insurance in something resembling its modern form emerged during the 16th and 17th centuries in England, France, and Holland, although the first life insurance policies may date back to 1800–1200 B.C. Grier[3] points out that life insurance policies existed in Spain by about 1100 A.D. and that "tontines" were highly popular in 17th century France. (Members of tontines made payments into a general fund; if one lived long enough one received a share of the pool; and if one were the last member of the tontine to remain alive one could become quite rich.) In England, the first recorded life insurance policy was issued in 1583. Life insurance then grew rapidly under the sponsorship of the various so-called Friendly Societies.

Historical records show that the failure rates of the English Friendly Societies were initially exceedingly high. In 1867, for example, an official of the British government estimated that during the previous 75 years one-third of the Friendly Societies had failed. The reason for the high rate of failure seems clear. Methods of probabilistic assessment were either not known or not utilized, and comprehensive sets of vital statistics were not available. Without appropriate tools for quantitative thinking about risk or the requisite data base, attempts to think quantitatively about risk often went awry. It was not until professional actuaries became an integral part of the industry in the 19th century that insurance companies stood on a firmer footing.

Developments in the life insurance field in the 17th century appear to foreshadow the modern debate concerning whether it is acceptable to place a monetary value on the loss of human life. The Church in particular raised serious questions about the morality of life insurance. For the Church, life insurance was an immoral—or at least highly suspect—wager on human life. Indeed, life insurance was prohibited in France until 1820. Debate about the morality of life insurance has long since died out, but similar issues are still discussed in debates about the moral status of cost–benefit analyses addressing risks to human life.

4.2. Common Law

In the English and American legal systems, the common law (that is, judge-made law) of "torts" has long permitted one citizen to recover damages from another for harms resulting from such actions as *nuisance* (use of one's own property that unreasonably interferes with the use of another's property), *negligence* (conduct that unreasonably imposes risks on another), and the pursuit of *abnormally dangerous activities*. These grounds for lawsuits amount to risk management in the sense that people must conform to a standard of reasonable conduct (e.g., cleaning their chimneys, disposing of waste products) or face the prospect of being liable and successfully sued for damages. Common law thus provides two risk management functions—compensation and deterrence.

Hammer[46] has argued that the origins of modern liability laws can be traced back to the Code of Hammurabi and to the Old Testament, both of which stressed the notion of *strict liability* (i.e., the concept that the manufacturer of a product is liable for injuries due to defects regardless of negligence or fault). With the advent of the Industrial Revolution, however, the principle of strict liability embodied in ancient laws fell into temporary decline, and proof of negligence or other fault on behalf of the defendant became an essential requirement for recovery of damages in most areas of common law. By 1850, the law stated that "the plaintiff must come prepared with evidence to show that the intention was unlawful, or that the defendant was at fault; for if the injury was unavoidable, and the conduct of the defendant was free from blame, he will not be liable." An injured party could seek redress only if there were proof of negligence and, according to the principle of *privity*, only from the party contracted to supply the product.

In the United States, it was not until 1916—in the MacPherson vs. Buick Motor Company[4] case—that this historically new and narrow concept of liability was partially broadened. In this case, it was ruled that the manufacturer had a responsibility to inspect products for defects, and that the lack of privity should not affect a plaintiff's right to recover damages for his injuries. It was not until the 1960s that the ancient notion of strict liability began to be reinstated through a series of court decisions and the passage of legislation that weakened the necessity to prove negligence in order to collect damages.

4.3. Direct Government Intervention

Since ancient times, government authorities have directly intervened to reduce, mitigate, or control risks. As Handler[47] pointed out, it "...has long been a function of government to shield the citizenry from those dangers against which it cannot readily protect itself; hence police and fire departments, armies and navies."

Many of the earliest efforts by government authorities relied heavily on magico-religious practices. In 5th century B.C. China, for example, provincial officials and priests required the annual sacrifice of a maiden to propitiate the Yellow River gods and thereby control the ravages of annual flooding, as is described in the following passage:

> "Adorned in ceremonial regalia, the victim was flung into the stream, where she was swiftly dragged beneath the surface by her heavy accouterments. Needless to say, the maiden was invariably selected from a peasant family rather than from the local gentry, and Chinese historians record that as the years passed, farmers who had eligible daughters deserted the district in increasing numbers. Eventually, around 400 B.C., a magistrate named Hsimen Pao stepped forth and put an end to the practice with one final, highly appropriate, sacrifice: He had the priests and officials hurled to their deaths in the swirling yellow waters."[48]

Paralleling, and sometimes alternating with, these magico-religious techniques were direct government interventions based on firmer ground. The following section provides several examples of early interventions that predate present-day practices.

[4]See MacPherson vs. Buick, 217 New York 382, 111 N.E. 1050, 1916.

4.3.1. Natural Disasters

Virtually all of the great ancient civilizations (e.g., China, Maya, Egypt, and Mesopotamia) directly intervened to mitigate the effects of natural disasters. Historical records indicate, for example, that throughout history, governments have played a major role in developing and financing elaborate systems of flood control, including dams, dikes, and canals. One of the first efforts of this kind was recorded by the Roman historian, Pliny the Elder. Pliny noted that the Egyptian authorities had successfully devised an elaborate system for dealing with the risk of famine due to the periodic overflow of the Nile. Pliny reported the system as follows:

> "The Nile begins to rise at the next new moon after midsummer, the rise being gradual and moderate while the Sun is passing through the Crab and at its greatest height when it is in the Lion; and when in Virgo it begins to fall by the same degrees as it rose. It subsides entirely within its banks, according to the account given by Herodotus, on the hundreth day, when the sun is in the Scales... Its degrees of increase are detected by means of wells marked with a scale. The province takes careful note of both extremes; in a rise of 18 ft. it senses famine, and even at one of 19 1/2 ft. it begins to feel hungry, but 21 ft. brings cheerfulness, 22 1/2 ft. complete confidence, and 24 ft. delight. The largest rise up to date was one of 27 ft. in the principate of Claudius (1st century A.D.) and the smallest 7 1/2 ft. in the year of the war of Pharsalus (48 B.C.), as if the river were attempting to avert the murder of Pompey by a sort of portent. When the rise was to a standstill, the floodgates are opened and irrigation begins; and each strip of land is sown as the flood relinquishes it."

As protection against a bad year, Pliny noted that Egyptian authorities used data on flooding and crop surpluses to adjust the taxes leveled on crops harvested in the current season.

In addition to attempts to prevent or control disasters, government authorities have also responded by providing relief after disasters occur. In 1803, for example, the U.S. Congress passed legislation to assist victims of a fire in Portsmouth, New Hampshire. In following years, Congress approved on an *ad hoc* basis more than 100 separate acts granting relief after specific disasters had occurred.[49] It was not, however, until the 20th century that the first U.S. agency was authorized to make loans to the private sector for rehabilitation, repair of damage, and alleviation of hardship caused by natural disasters.

4.3.2. Epidemic Disease

Throughout history, government authorities have attempted to mitigate the effects of epidemic disease. The magnitude of the problem was in many cases staggering. The 1348 to 1349 epidemic of the Black Death (bubonic plague), for example, killed over a quarter of the population of Europe—approximately 25 million people.[50-52] Given the lack of knowledge about the causes of diseases such as plague and typhus, government authorities often adopted one of the oldest and most direct strategies of disease control—quarantine and isolation. Fear of leprosy, for example, has throughout history caused wide-scale adoption of the practice of isolating the infected and the cleansing or burning of their garments. Fear of infection also prompted healthy communities to adopt strict measures in preventing the entry of goods and persons from infected communities. In the 7th century A.D., for example, armed guards were stationed between plague-stricken Provence and the diocese of Cahors. One thousand years later, in 1720, when Marseilles was suffering a severe epidemic of the plague, a ring of sentries was placed around the city to prevent any person from escaping.[53,54]

In addition to quarantines and public health efforts (discussed below), the development of vaccines in the 18th and 19th centuries had a major impact on the problem. Although governments played only a minor role in these developments, it is interesting to note that the first federal regulatory health statute in the United States was the Federal Vaccine Act of 1813.[55] The act gave the President the power to appoint a federal vaccine agent to test the safety of the newly discovered smallpox vaccine. The law was repealed, however, in 1822 on the ground of "states rights."

4.3.3. Pollution

Pollution of the air, water, and land has long been recognized as a problem, but efforts at pollution control have been highly sporadic. Air pollution (due to dust and smoke from wood and coal fires) has been a ubiquitous problem in congested urban areas since ancient times.[25] The first act of government intervention did not occur until 1285, however, when King Edward I of England responded to a petition from members of the nobility and others concerning the offensive coal smoke in London. Smoke arising from the burning of soft coal had long been a problem in London.[14,56] Edward's response to the petition was one that is now commonly practiced by government risk managers—he established a commission in 1285 to study the problem. In response to the commission's report, several private sector actions were taken, including a voluntary decision by a group of London smiths in 1298 not to "...work at night on account of the unhealthiness of coal and damage to their neighbors."[56] These voluntary efforts were not sufficient, however, and in 1307 Edward issued a royal proclamation prohibiting the use of soft coal in kilns. Shortly after this, Edward was forced to establish a second commission, the main function of which was to determine why the royal proclamation was not being observed.

The history of water and land pollution control has been equally sporadic. Over three thousand years ago, the governments of Minoa and Crete built community sewage-drainage systems, and at least some citizens enjoyed the benefits of flush toilets and indoor plumbing.[57,58] Athens and other Greek cities also built sewage-disposal systems and enacted laws requiring that waste matter be carried outside the walls for a certain distance before it was dumped. Fines were frequently levied and pollution of the city water supply could merit the death penalty.[25] The ancient Romans, however, are credited with developing the most extensive system, consisting of paved streets, gutters, and a complex of tunnels and aqueducts.[52,59] Roman authorities also enacted strict laws to control foul smells and the disposal of waste products.[57] After the fall of the Roman Empire, many of these laws were unfortunately forgotten and the structures fell into disrepair. A resurgence of interest did not appear again until the 14th and 15th centuries when, in response to the spread of contagious diseases, public officials in Europe created a rudimentary system of pollution and sanitary control. The system included the development of pure water supplies, garbage and sewage disposal, observation stations, hospitals, disinfection procedures, and food inspection. The extent and effectiveness of these efforts should not, however, be overestimated. As several authors have noted (e.g., Bettman[60]), prior to the 19th and 20th centuries:

> "...filth, squalor, and disease of community life were apparently accepted as a usual and normal state of affairs. The crude attempts to alleviate the conditions of those days were almost always local efforts. The situation was aggrevated by the Industrial Revolution, when hordes of men, women, and children flocked to the cities seeking employment in the new factories. The cities, utterly unprepared to meet the influx, had no means of housing the newcomers except in areas where living conditions were already wretched. To make matters worse, flimsy tenements were improvised without proper provision for ventilation, light, water, and waste disposal. Streets were dark, narrow, and barely passable owing to filth, stagnant pools, and the stench arising from them. Inevitably, the drinking water became contaminated, and as a result typhoid, dysentery, and cholera took a large toll of lives."[61]

In dealing with these problems, public health efforts were seldom effective. Despite the passage of laws by many localities, such as the 17th century ordinance enacted by colonial New Amsterdam prohibiting "...the throwing of rubbish and filth into the streets and canals,..."[62] and a law passed in 1671 requiring that each peasant coming into Berlin had to leave with a load of filth,[59] little change took place until the 19th century. One factor contributing to the changes that occurred in the 19th century were a number of government-sponsored reports documenting the abominable conditions in European and American cities. In England, Edwin Chadwick published his classic work *Report on an Inquiry into the Sanitary Conditions of the Laboring Population of Great Britain in 1842*. This report, which was commissioned by the British Parliament four years earlier, played a major role in the creation of the General Board of Health for England in 1848. Similarly, in the United States, Lemuel Shattuck's publication of his *Report of the Sanitary Commission of Massachusetts* (1850) led to the establishment of the State's Board of Health in 1869. The act creating the Board directed it to:

> "...make sanitary investigations and inquiries in respect to the people, the causes of disease, and especially of epidemics, and the source of mortality and the effects of localities, employments, conditions, and circumstances on the public health; and they shall gather information in respect to those matters as they may deem proper, for diffusion among the people".[57]

Over the next few decades, several localities in the U.S. and Europe created similar bodies, leading to major improvements in street paving, refuse collection, water purification, water distribution, and sewage disposal. Several important laws were also passed including the English Nuisance Removal Act of 1855 which attempted to regulate gross pollution of the Thames River. Unfortunately these laws were seldom heeded (see Ref. 63), and effective pollution controls occurred only after major outbreaks of infectious diseases.

4.3.4. Food Contamination and Adulteration

As the basic sustenance of life, virtually all societies have been concerned about the safety of the food supply. The Biblical abominations of Leviticus, particularly the prohibition against the eating of pork, are often cited as an early attempt at controlling food safety. Douglas[64] has argued, however,that it would be a mistake to view all such attempts as simple forerunners of modern food and drug regulations. She observes that food prohibitions often serve a variety of purposes, including: the affirmation of ethical norms, a means of distinguishing one group from another, and a symbolic mechanism for bringing order into a chaotic world by classification and category. (see also Douglas and Wildavsky[65]) In her discussion of Leviticus, she asks:

> "Why should the camel, the hare, and the rock badger be unclean? Why should some locusts, but not all, be unclean? Why should the frog be clean and the mouse and hippopotamus unclean? What have chameleons, snakes, and crocodiles got in common?"[64]

In response, Douglas suggests that the abominations of Leviticus can be seen as a mix of pragmatic-classificatory rules and the threefold classification of Genesis which divided creation into the earth, sea, and sky. "Clean" animals fully conform to the archetypes of their class: cloven-hoofed ruminants; four-legged animals of the earth that hop, jump, or walk; scaly fish of the sea that swim with fins; and two-legged fowls that fly with wings. Species that are "unclean" are those that are imperfect members of their class, or whose class itself violates the Biblical system.

Aside from the Biblical prohibitions, it appears that the first important law to be enacted regulating food was the English Assize of Bread (1263), which made it unlawful to sell any food "unwholesome for man's body." Interestingly, Hutt[55] has argued that this statute is practically indistinguishable from the current U.S. standard prohibiting additives which "may render food injurious to health." For nearly six hundred years, the Assize of Bread and later statutes covering other food products were in effect until many were repealed in the early 1800s at the height of the industrial revolution and a *laissez faire* philosophy of government. By the late 19th century, however, the medieval laws were reinstated, culminating in federal legislation such as the U.S. Biologies Act of 1902, the Federal Pure Food and Drug Act of 1906, and the Federal Meat Inspection Act of 1906. (The earliest food adulteration act enacted by a state had been passed more than a century earlier in 1785 by Massachusetts.)

4.3.5. Building and Fire Codes

In what is perhaps the first recorded attempt to manage risks through government regulation, the Code of Hammurabi (circa 1950 B.C.) decreed that should a house collapse and kill the occupants, the builder of the house must forfeit his own life.[45,66] Although not quite as strict, the Romans also enacted laws regulating the quality of building constructing.[57] Aside from construction risks, virtually all societies have been concerned with the risks of fire. Despite this concern, however, it appears that a concerted effort by government to deal with the problem did not occur until the 17th century. In 1626, for example, the Plymouth colony enacted a law directing that new houses not be thatched, but roofed with board or other materials.[67] In 1648, New Amsterdam prohibited the construction of wooden or plaster chimneys on new homes, and required that chimneys on existing homes be inspected regularly. An even stricter abridgement of individual freedom occurred in 1740 when the city of Charleston required that "...all buildings should be of brick or stone, that all 'tall' wooden houses must be pulled down by 1745, and that the use of wood... be confined to window frames, shutters, and to interior work."[68] The event of perhaps the greatest significance in stimulating government authorities to action was the Great London fire of 1666, which destroyed over three-quarters of the city's buildings. Largely as a result of this disastrous fire, nearly all large cities in Europe and America established municipal fire extinguishing companies during the next hundred years.

4.3.6. Transportation Accidents

Regulation of the transportation system, in the interest of safety, substantially predates modern mechanized transportation technologies. Traffic safety regulations, for instance, date back at least to ancient Rome. According to Hughs,[25] a municipal law under Julius Caesar prohibited all wheeled vehicles to operate in Rome between sunrise and 2 hours before sunset, except for essential public service traffic. This regulation was largely for the benefit of pedestrians, for whom the combination of narrow streets and heavy traffic created a genuine hazard.

The highly regulated character of the modern transportation system was foreshadowed by responses to earlier technological developments. Indeed, the first regulation of a technological risk in the United States occurred in 1838, when Congress passed legislation governing boiler testing, inspection, and liability.[69,70] This legislation was enacted in response to a series of boiler explosions on steamboats that led to thousands of injuries and fatalities during the early 19th century. The initial legislation was too lax to foster effective risk reduction, but was replaced by stricter legislation in 1858. This law specified engineering safety criteria, gave inspectors authority to examine boats and refuse licenses, and created a regulatory agency—the Board of Directors of Inspectors.

The steamboat remained the dominant form of transportation technology in the United States until the latter part of the century, when it was replaced by the railroad. Both in the United States and Europe, disputes over the risks of railroads clearly reflected broader social values. The major concerns in Britain regarding this new transportation technology were described by Cohen[71] as "horror at attaining speeds over 40 kilometers an hour, concern about the capacity of new kinds of organizations to run large operations safely, fears of social consequences of change, worries about the desecration of the Sabbath, and even concern at the ease with which dangerous radicals might travel about the country." At the turn of the 20th century, disputes about the automobile also reflected social concerns broader than those associated with risk.[70] For both the railroads and automobiles (and later airplanes), the substantial intrinsic risks associated with these transportation modes led quickly to the development of a regulatory scheme that, while much stricter today than in its earliest versions, is not essentially different in concept.

4.3.7. Occupational Injuries

Prior to the 18th and 19th centuries, occupational health and safety issues were apparently of only minor concern to government authorities. Although working conditions in most industries were generally abominable (e.g., see Agricola[26] and Engels[72], it was not until the Industrial Revolution that government officials took note. Most of the first efforts by government authorities were focused on the conditions of child labor.[73] As Samuelson has noted,

> "...No Dickens novel did full justice to the dismal conditions of child labor, length of working day, and conditions of safety and sanitation in the early nineteenth century factories. A workweek of 84 hours was the prevailing rule, with time out at the bench for breakfast and sometimes supper, as well as lunch. A good deal of work could be got out of a six year old child, and if a man lost two fingers in a machine, he still has eight left."[74]

In 1842, a British Parliamentary commission estimated that about one-third of the mine workers in Britain were less than 13 years old. The commission's report noted that many of these children were employed as "trappers," who manned the air doors that separated the various sections of the mines. Their life consisted of sitting "...in the pit the whole time it is worked, frequently above 12 hours a day. They sit, moreover, in the dark, often with a damp floor to stand on, and exposed necessarily to drafts... ."[75]

Most efforts at reform were initially strongly resisted by mine and factory owners, although there were a few notable exceptions. The 19th century British millowner Robert Owen, for example, played an important role in bringing about change through the way he operated his mills and through his writings about the responsibility of employers toward their employees.[76]

At the same time that improvements in working conditions were being made, significant changes were also taking place in the way societies dealt with work-related accidents and occupational diseases. In the late 19th century, workers' compensation statutes were enacted in Germany under Bismarck. Within 20 years, similar laws were passed in England and by a number of states in the United States.[77] Under these laws, requirements to demonstrate employers' negligence or fault were waived for most occupational injuries and an employee was entitled to compensation based on a percentage of lost wages.

4.4. Private Sector Self-Regulation

Insurance, common law, and government intervention are not, of course, the only societal strategies for managing risks. Voluntary, private self-regulation aimed at preventing or reducing potential adverse health effects has always played an important part in societal risk management efforts. In virtually all societies, there have been strong incentives for the private sector to refrain from actions that would recklessly endanger the health of the public. Such incentives range from moral and altruistic norms and values to simple self-interest based on fear of monetary loss, possible civil or criminal litigation, or punitive or restrictive government action.

Private risk management activities are intrinsically less publicly obvious than other risk management strategies. Two of the more visible forms of this strategy are industrial self-regulation and licensure and certification.[78] Both these types of voluntary self-regulation, however, appear to have few clear historical precedents prior to the late 19th and early 20th centuries.

4.4.1. *Industrial Self-Regulation*

Reliance on privately-developed standards is particularly widespread at the local level and in areas such as fire safety and the provision of electrical, building, boiler, plumbing, and similar services. Baram[78] points out that such reliance is virtually a necessity given the characteristically limited technical and financial resources available at local governmental levels. He observes that historical experience suggests two essential conditions for the successful use of this type of strategy in risk management: (1) the involved risks and technologies must be well understood, (2) the potential liability must be significant enough to force a responsible industrial approach to risk reduction.

Perhaps the most important institutional mechanism for industrial self-regulation are the standard-setting organizations, professional and technical societies, trade societies, and testing laboratories that set consensus-based standards covering a wide variety of products, materials, systems, services, processes, and practices. Such organizations were, for the most part, founded during the late 19th and early 20th centuries in growing recognition of the hazards associated with increased industrialization. Major standard-setting organizations include the American Society of Mechanical Engineers, founded in 1880; the Underwriters Laboratory, founded in 1894; the National Fire Protection Association, founded in 1896; the American Society for Testing and Materials, founded in 1898; and the American National Standards Institute, founded in 1918.

4.4.2. *Licensure and Certification*

Although over 550 occupations are currently licensed in the United States, licensing and certification appear to have been little used as a form of risk management prior to the turn-of-the-century. Surprisingly, this appears to have been true even for such clearly risky and currently heavily regulated areas as medicine. The control of physicians in the U.S. by licensure first began in the eighteenth century but was abandoned from 1820 to 1850. Our present form of physician licensure did not really begin until the late 1800s.[78] The system of licensure that evolved, however, has often been criticized as serving economic self-interests (e.g., by excluding competition) as much as protecting public health and safety.

5. NINE IMPORTANT CHANGES BETWEEN PAST AND PRESENT

It should not be surprising that contemporary ways of thinking about, and coping with, risks are different in many respects from earlier times. In this century, especially in the last few decades, major changes have taken place in the nature of the risks that society faces, as well as in the social and political context for risk analysis and risk management efforts. Nine changes between past and present that we consider among the most important for risk analysis and risk management are discussed below.

5.1. Shift in the Nature of Risks

In the United States, the leading causes of death in 1900 were infectious diseases—pneumonia, influenza, and tuberculosis.[79] By 1940, infectious diseases had been displaced by two chronic degenerative diseases of adulthood—heart disease and cancer. Although there has been no substantial change in the rank of accidents as another leading cause of death, there has been a shift in the types of accidents to which human beings are subject. The rate of fatal accidents in British coal mines, for example, fell from 4 per 1000 workers in the mid-19th century to less than 1 per 1000 workers in recent decades. Similarly, the average annual rate of fatal accidents in British factories fell from 17.5 deaths per 100,000 employees seventy years ago to a recent rate of less than 4.5 deaths.[80] Natural hazards still cause substantial property damage, but in industrialized nations such events account for only a small number of annual fatalities. While these types of accidents have been declining in significance, other types have increased. In 1900, the number of automobile accidents in the United States was, understandably, insignificant; however, in 1980 automobile accidents accounted for over 50,000 deaths.[81]

5.2. Increase in Average Life Expectancies

A female born in the United States in 1900 could expect to live, on the average, 51 years; a male born in the same year could expect to live 48 years.[79] But a female born in 1975 could expect to live for 75 years, and a male born in the same year could expect to live to 66. Looking further back in history, the average life expectancy was about 33 years in the Middle Ages, 20–30 years during the Roman Empire[82] and 18 years in prehistoric times.[83,82,84] The factors leading to these increases are complex and not entirely understood, but certainly include substantial improvements in nutrition, hygiene, sanitation, working conditions, education, standards of living, and medical services.

5.3. Increase in New Risks

There has been an increase in new risks fundamentally different in both character and magnitude from those encountered in the past. These include nuclear war, nuclear power plant accidents, radioactive waste, exposure to synthetic pesticides and chemicals, supertanker oil spills, chemical plant and storage accidents, recombinant DNA laboratory accidents, ozone depletion due to emissions of fluorocarbons, and acid rain. The magnitude of many of these risks cannot easily be estimated because historical or actuarial data do not exist or are extremely difficult to collect. Moreover, cause–effect relationships are often highly problematic for these risks. Of perhaps greatest importance is that many of these new risks are latent, long-term, involuntary, and irreversible. At least some are conceivably globally catastrophic, and most are derived from science and technology (in contrast to risks from "acts of nature or God").

5.4. Increase in Ability of Scientists to Identify and Measure Risks

These improvements include major advances in laboratory tests (e.g., animal bioassays and *in vitro* tests), epidemiological methods, environmental modelling, computer simulations, and engineering risk assessment (e.g., fault trees and event trees). Because of these advances, scientists are now routinely able to detect design faults in extremely complex engineering systems; even weak causal links between hazards and deleterious outcomes; and infinitesimally small amounts (e.g., parts per trillion) of potentially harmful carcinogenic or mutagenic substances.

5.5. Increase in the Number of Scientists and Analysts Whose Work is Focused on Health, Safety, and Environmental Risks

In recent years risk analysis has emerged as an identifiable discipline and profession, with its own societies, annual meetings, journals, and practitioners. In the last decade alone, the risk analysis literature has grown from a handful of articles and books to a formidable collection of material.[85]

5.6. Increase in Number of Formal Quantitative Risk Analyses that are Produced and Used

In the past, risk management decisions were based primarily on common sense, ordinary knowledge, trial and error, or nonscientific knowledge and beliefs. In recent years risk management decisions have been increasingly based on highly technical quantitative risk analyses. Increased reliance on such analyses reflect a related trend—a growing societal preference for planning, forecasting, and early warning in contrast to *ad hoc* responses to crisis.

5.7. Increase in Role of Federal Government in Assessing and Managing Risks

There have been dramatic increases in: (1) the number of health, safety, and environmental laws, with over 30 major pieces of federal legislation passed within the last two decades; (2) the number of federal agencies charged with managing health, safety, and environmental risks; including the Environmental Protection Agency, the Occupational Safety and

Health Administration, the Consumer Product Safety Commission, the National Highway Traffic Safety Administration, and the Nuclear Regulatory Commission; and (3) the number of health, safety, and environmental cases adjudicated by the courts both in the tort-liability system and in judicial review of agency decisions.[86-88] Although attempts have recently been made to reverse the trend toward growth in federal regulatory involvement, several factors have contributed to its continuation, including the increasing health, safety, and environmental consciousness of the nation; a decline in the level of public confidence in business; the emergence of the public interest movement; and the growth of a complex, interdependent, highly technological society.[86] Additional factors leading toward continued federal regulatory involvement include the following:

- An accelerating rate of technological change, resulting in enormous increases in the physical and temporal scale and complexity of risks (for example, approximately 70,000 chemicals are in current use, with perhaps 1000 new chemicals being introduced each year).[79]
- An increase in the speed of scientific and technological developments, so that there are shorter and shorter time lags between scientific experimentation, technological development, and entrepreneurial production.
- The increasing role of government as a producer of risks through its sponsorship of scientific and technological research and development.
- The rising cost of technological risk control and damages—estimated by one research group[89] to be 179–283 billion dollars a year.

5.8. Increase in Participation of Special Interest Groups in Societal Risk Management

Risk analysis and risk management activities have become increasingly politicized, with virtually every major health, safety, and environmental decision subject to intense lobbying by interest groups representing industry, workers, environmentalists, scientific organizations, and other groups.[70] Not only has there been a substantial increase in the number of such groups and their members, but also substantial growth in their scientific sophistication and modes of operation. These changes have contributed to at least two others: (1) It has become increasingly necessary for government decision makers to consult representatives from these groups and to make risk analysis information publicly available. (2) The adversarial nature of most contemporary risk debates appears to be causing increasing confusion among the public (due in part to the inscrutability for the layperson of competing technical risk analyses and the widely publicized and often heated debates between scientists).

5.9. Increase in Public Interest, Concern, and Demands for Protection

Despite increases in average life expectancies, reductions in the frequency of catastrophic events, and assurances that "the health of the American people has never been better,"[90] surveys indicate that most Americans believe that life is getting riskier. A recent Louis Harris[91] poll found that approximately four-fifths of those surveyed agreed that "...people are subject to more risk today than they were 20 years ago." Only 6% thought there was less risk (although it should be noted that the definition of *risk* implied in the survey questions may have been considerably broader than the meaning used in this paper). Research has suggested that the primary correlates of public concern are not mortality or morbidity rates, but characteristics such as potentially catastrophic effects, lack of familiarity and understanding, involuntariness, scientific uncertainty, lack of personal control by the individuals exposed, risks to future generations, unclear benefits, inequitable distribution of risks and benefits, and potentially irreversible effects.[92,93] Many of the most salient contemporary risks—nuclear power plant accidents, nuclear waste, airplane crashes, exposure to toxic chemicals, ozone depletion, exposure to low level radiation, recombinant DNA, acid rain—possess precisely these characteristics. Additional factors contributing to heightened public concern include a better-informed public, the seemingly weekly scientific discovery of previously unknown risks, advances in communication technologies leading to widespread and intensified media coverage of risk problems, rising levels of affluence accompanied by expectations of decreasing risks, rising expectations about the ability of science and technology to control risks, and loss of confidence in the major risk management institutions in contemporary industrialized societies—particularly, business and government.[86]

6. IMPLICATIONS FOR THE FUTURE

Making projections about the future is always a risky enterprise, especially in an area as complex as risk analysis and risk management. Nonetheless, a historical perspective suggests certain trends that can reasonably be expected to be important in the foreseeable future.

We expect that public concern about risk will continue to increase, and we expect this to occur in spite of the simultaneous trend toward longer, healthier lives. Part of this is due to the changing nature of the risks faced by modern society, including increases in the number of "mysterious" technological hazards offering prospects of dread, ill-understood, or potentially catastrophic consequences. But the more profound change may be the increasing prevalence of the idea that injuries, deaths, and diseases are not acts of God to be fatalistically accepted, but avoidable events subject to some degree of human control. This change in perspective implies that something *can* be done about most risks. Paralleling this is a change in perspective implying that something *should* be done—derived in part from changing ideas about the rights of individuals to live their lives free of risks imposed on them by others and about the role of government in protecting individuals from such risks.

Improved scientific, technical, and engineering capabilities should lead to steady improvements in our ability to control, reduce, or eliminate risks. The same set of capabilities are also expected to lead, however, to steady increases in the number of identified risks. In the near term, we suspect that improved risk management capabilities will be outstripped by improved risk identification capabilities. Although improved risk management will be welcome, improved abilities to identify and measure risks will not necessarily lead to feelings of greater understanding or control. Indeed, we expect just the opposite. Already, improved science has raised more questions than it has settled about the possible risks of both new and familiar objects, substances, and activities.[94,95] This phenomena might be dubbed the "Hydra effect"—for every risk problem that is resolved, two new ones are raised in its place (Baram, personal communication). It is quite likely that the probabilistic and uncertain world created by modern science and technology will seem to many an increasingly risky and uncomfortable place, even in the face of overall improved prospects for a longer, healthier life.

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