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Risk Analysis

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This paper presents a literature review on risk analysis. Risk has been defined in different ways, depending on the decision making context. Risk measurement is usually done through probability assessments and subjective judgments, either by the decision makers or by experts. These are explored, together with the concept of uncertainty and the different decision making tool used in risk analysis. Decision analysis, utility theory, multiattribute utility theory, and the analytic hierarchy process are the most widely used risk assessment techniques used. There is a need to assess the actual use of risk assessment techniques. A survey designed to evaluate the usage of such techniques among companies in different industries is recommended.

RISK ANALYSIS

A survey of the literature on risk analysis indicates several other interrelated and important fields of study. Closely related to the concept of risk is uncertainty. Risk and uncertainty are inherent in business situations, particularly in the area of strategic planning. To deal with both risk and uncertainty involves the use of decision making skills and tools. The more important tools used to assess risk are utility theory, multiattribute utility theory, and the analytic hierarchy process. There are numerous articles expounding on these concepts and their extensions and applications. however, several articles have also identified possible problems in these concepts. Consequently, new approaches have been proposed.

The purpose of this paper is to provide a snapshot of what is currently being done in risk analysis and identify research gaps. The literature is divided into several subheadings. I will begin by noting the different definitions of risk and uncertainty, and how they relate to decision making. This will be followed by risk measurement and analysis. Next, the application of risk analysis in the business setting is considered.

Decision analysis in general, the use of experts in assessing risks, utility theory, multiattribute utility theory, and the analytical hierarchy process will be discussed next. Different approaches in decision making under risk will be explored. An attempt to identify research gaps will follow an evaluation of the literature gathered so far.

Definitions of Risk

Risk has been defined in various ways in textbooks. Baird and Thomas [4] attempted to provide a broad conceptualization of strategic risk taking. They defined it as "corporate strategic moves that cause returns to vary, that involve venturing into the unknown, that may result in corporate ruin." In these moves, the outcomes and probabilities of these outcomes may only be partially known, and that there is no guarantee that these goals will be met [4, p.231]. The relevant dimensions of strategic risk [4] were taken from Vlek and Stallen's [50] work. These are voluntariness of exposure, controllability of consequences, distribution of consequences in time, distribution of consequences in space, context of probability assessment, context of accidental evaluation, combination of accident-probability, and seriousness. Souder [47] considered three kinds of risk in the context of new product development. Technical risk is the potential for loss or harm in design or manufacture which are related to the technology being used; market risk refers to the potential harm due to factors such as competition, changing customer needs, pricing, and other market factors; and business risk which refers to possible harm brought about by economic, political, social, and other aspects of the business environment [47, pp. 186-187].

Uncertainty exists when problem structures, consequences, and probabilities are not fully known. Hence there is an overlap between risk and uncertainty [4]. Fishburn [17] surveyed conventional wisdom in several fields which indicated that risk "is the chance of something bad happening", and that uncertainty is not taken as an inherent part of risk. However, Russell and Ranasinghe [38] considered risk and uncertainty as synonyms in their attempt to quantify economic risk for large engineering projects. Tversky and Kahneman [48] explored the heuristic

that are used in making judgments under uncertainty.

In an attempt to clarify various meanings of risk, Sjoberg [45] identified three broad classes: "those concerned with the probability of negative events, those concerned with the negative events themselves measured in some suitable way, and those concerned with a joint function of probability and consequences." [45, p.302]. In the business setting, Libby and Fishburn [32], and Woo [53] saw that variance or dispersion of outcomes are used as suitable representations of risk. Finally, Collins and Reufli [8] viewed risk as "a measure on the chance of loss of relative position within a group of firms".

The key element in any risk assessment methodology is to clearly state a definition of risk that is appropriate to the study being conducted.

Risk Measurement and Analysis

Vlek and Stallen [50] explored the fundamental aspects of risky decisions broadly, how they related to one another, and how humans may possibly react. Risk measurement has been explored by Fishburn [17,18,32] in a more formal and mathematical context. He addressed risk measurement from an axiomatic perspective, more specifically, proposing conditions on the relation "is at least as risky as" [17, p.396] between pairs of probability distributions which govern an outcome variable. In his other article, Fishburn [18] discusses the "measures of risk that include effects of gains on perceived risk". He argued two main points: increased gains

reduces the risk of fixed probable losses without completely negating that risk [18, p.226] and that there is no risk involved when prospects with no chance of loss are considered.

Risk analysis in the business setting can take different approaches [32,38,45,47]. Libby and Fishburn [32] surveyed and classified the structures for models used in risky choices. The model validity of these models as predictors of actual business behaviors were also studied. Applications of risk measurement include the economic risk quantification of large engineering projects [38], where risk and uncertainty are considered synonymous, using a framework based on moment analysis. Risky technologies were assessed using risk analysis tools [45]. This application showed the limitations of risk analysis when a highly provocative subject such as the assessment of technological risks is involved. Other measures of risk include ordinal rankings of firms [8], and a model which incorporates organizational, industrial, and environmental concerns [4].

Business Applications

A firm's strategic decision making should incorporate the effects of its environment [6,19,24] as well as technological innovations [10], R&D [37], and rivalry [40]. Technological innovations, competition, regulation [42] will certainly affect the magnitude and types of risks that any firm will face. Firms must clearly define its position vis-a-vis its competition in the market and monitor what they are doing. There are interactions among the firms in an industry which affects how a firm defines its strategy.

Collins and Reufli [8] used an ordinal approach to risk which takes into account the interactions among firms in a certain industry.

Assessment of risk in R&D projects is critical because of the lag structure of the returns associated with it [37]. Revenues are directly related to completion time, end product quality, and competition reaction, while costs are tied to technology, quality, and speed of development [40].

The type of information for decision making under risk is critical. This will depend on the type of decisions to be made, the context, and the complexity of the task [19]. Another group of articles focused on the relationship between risk and return [7,25,34,44,53]. The studies indicate a departure from the traditional notion about the positive relationship between risk and return. The results of Bowman's study [7] gives reasons to doubt this positive relationship. Singh's study [44] went further as to indicate a negative relationship between risk and performance. Miller and Bromiley [44] looked at the effects of risk on performance and vice versa. Their study indicate that high performance reduces subsequent income stream uncertainty, while low performance increased income stream risks.

Decision Making

Judgment and decision making process under risk and uncertainty have been facilitated by the use of subjective probabilities. There are numerous probability encoding methods used and proposed. Spetzler and Von Holstein summarized the methods used by the Decision

Analysis Group at Stanford University [46]. Their approach consisted of pre-encoding steps, the use of only ordinal judgments, the use of a reference process (e.g. probability wheel), and several techniques for checking consistency [46, p.357]. Mintzberg, Raisinghani, and Theoret [35] conducted a field study of 25 strategic decision processes. They suggest that there is a basic structure underlying these "unstructured processes". These processes were described and a general model elaborating the interrelationships among them is proposed.

Judgments under uncertainty can be facilitated by the use of heuristics. These heuristics can be highly economical. However, they lead to systematic and predictable errors [48]. Measurement and psychometric theory can be used to derive a general framework for assessing and evaluating subjective probability encoding schemes. "Reliability, internal consistency, calibration, external validity, and construct and inter-response correlation" are five categories which comprise the kinds of studies made to deal with the different psychometric characteristics of subjective probabilities [51,p.157].

The Use of Experts

It is not unusual that historical data are not adequate to estimate outcome probabilities. Complex technical problems [27] is an example of where expert judgment can be of tremendous importance. Huber [23] presented guidelines and methods for eliciting subjective probabilities, while Keeney and Von Winterfeldt [28] used two formal elicitation processes to extract

probabilities from experts in a large-scale study concerning nuclear safety. They say that expert judgments have attracted more attention. Hence, there is a need for accountability and defensibility is using analyses which involve expert input. Eckenrode [12] conducted a study "to identify the efficient and reliable methods for data collection on human judgments of the relative value of a list of items". Six methods were considered and the results indicate that there were no significant differences in any of them in terms of reliability and time efficiency.

The probability assessments of several experts in one particular field can be conflicting. Morris [36] explained the existence of a composite probability function that measures the information contained in the probability assessments of a panel of experts. Whether there are one or more experts involved, normalization and calibration may both be necessary. Wallsten and Budescu [51] studied the difference in calibration between experts and non-experts and found out that experts can be exceedingly well- calibrated when encoding subjective probabilities about events they are familiar with. Expert judgments are then changed into multiattribute utilities.

Utility Theory

The utility assessment process is a part of the decision analysis methodology. Farquhar [15] identified the different methods as being grouped into equivalence methods, preference comparison methods, probability equivalence methods, certainty equivalent methods, hybrid methods, and paired-gamble methods. Schoemaker [41] evaluated five conceptually different approaches used in additive utility models [41]. On the other hand, King [29] studied different

techniques that were designed for use in the four phases of applied decision analysis. These are problem formulation, determination of subjective probability distributions, measurement of decision maker preferences, and the identification of preferred choices. He also presents an approach that permits the construction of interval measurements of a decision maker's absolute risk aversion.

Applications of Utility Theory can be found in agricultural risk modelling [30], and the econometric estimation of farmer's risk aversion. However, there are some problems in the use of Utility

Theory. Greer [21] hypothesized that there is a basic conflict between Utility Theory and actual risk tolerance decision processes. He argues that classical Utility Theory fails to synthesize the actual decision process. This resulted in lack of practitioner practice. Decision makers have the tendency to be more risk averse at the time of actual choice than what his or her per-decision statements were.

Multiattribute Utility Theory (MAUT) has also been used to assist group decision making under risk and uncertainty. There are additive and multilinear forms of MAUT, and Eliasberg [13], showed that some families of utility functions can adequately describe the preferences of a large number of decision makers. Other MAUT studies deal with the comparisons of weighting judgments [5] and the investigation of the predictability of multiattribute elicitation procedures [20]. This study also presented guidelines on choosing among several multiattribute utility elicitation techniques.

Analytic Hierarchy Process (AHP)

AHP is argued to be a successful decision making tool because of its ability to structure and analyze [52]. "It provides a general theory of measurement for expressing both tangible and intangible factors" [53. p.57]. It can be used to handle complex problems in the following steps: "decomposition of the problem into a hierarchy of components or elements, determination of ratio weights for the elements of the hierarchy, and composition of the numbers obtained into overall weights which measure the decision outcome" [52, p.57]. AHP was used by Saaty and Vargas [39] to rank several alternatives.

Synthesizing judgments is crucial in AHP. If all efforts to reach consensus among a group of decision makers fails, then there remain judgments to synthesize [2]. Aczel and Alsina [2,3] used Saaty's simple geometric mean as a synthesizing function. The latter article is an in-depth mathematical approach used to identify the synthesizing function or a family of functions that contain the geometric mean. In another article [1], Saaty and Alsina investigates the requirements for functions synthesizing judgments. These are separability, associativity, cancellativity, consensus, and homogeneity. These were investigated in their article. All functions which satisfy them were determined. Finally, Dennis [11] developed an approach using the principle of hierarchical composition to analyze the assignment of priorities under uncertainty in hierarchically structured multicriterion decision problems.

Different Approaches

Several studies have departed from the more common study of risk analysis for different reasons. Kahneman and Tversky [26] proposed a "Prospect Theory" which evolved from their criticism about the used of expected utility theory as a model for decision making under uncertainty. They identified two problems in expected utility theory which they considered in their proposed prospect model. The "certainty effect" occurs when people overweigh outcomes which are certain as opposed to being probable; the "isolation effect" occurs when people discard components that are shared by all prospects under consideration [26,p.263]. Both these effects may lead to different preferences. This theory was applied in determining the influence of risk and uncertainty in logistics decision making [14].

Souder and Bethay [47] on the other hand, proposed a "risk pyramid" model which puts business risk, market risk, and technical risk as sides of a triangle. The bases are comprised by benefits, technology, and form. They defined the center of gravity as the "center of risk" which will move, depending on the interactions and magnitudes of the sides and bases. It measures the potential for product failure at different configurations of the triangle.

Evaluation

People still have difficulty in assigning utility and probability values in quantifying risk. Axioms governing expected utility theory are violated [31]. Furthermore, despite the availability of numerous statistical decision models, little attention has been given to actually applying them in the "real world" [9]. Conrath [9,p.873] addressed one aspect of the conversion process that

is necessary: the conceptualization of and use of use of probabilistic data for decision making. It seems that despite the tremendous growth of decision analysis models, there is still a gap between theoretical modelling and actual application.

Risk has been defined in several different ways, depending on the particular problem context. This is a necessary step because it will determine what kind of analysis is appropriate. Risk, and uncertainty as a related concept can best be grasped through the use of probabilities. These can be elicited using pairwise comparisons and other methods designed to have measures of reliability, consistency, etc. taken. Valuable information and subjective judgments from experts also need to be expressed in terms of probabilities.

Because of the necessity of having subjective probabilities, there is a need to formalize the procedures that can be taken in order to make justifiable decision-making criterion under risk and uncertainty. Utility theory, MAUT, and AHP attempt to incorporate theoretical concepts, with all their assumptions, axioms, qualifications, and methodology into the decision making process. Numerous articles propose new theories, different weighting schemes, and new measures of consistency and reliability, to name a few. While some have addressed the theoretical basis for synthesizing functions [1,2,3] in AHP, Fishburn approached risk measurement from a more formal and mathematical perspective [17,18].

I feel that there is enough theoretical justification for the current methods employed to quantify risk. However, there is still much work to be done in getting the actual decision makers to have a better grasp of the whole risk measurement and quantification process. The way to verify the usage of decision making tools under risk is to conduct a survey of companies

in different industries. Some relevant questions which may be asked are:

How is risk defined in your particular company? Do you consider uncertainty different from risk? Do you feel that your definition of risk is consistent with that of your competitors?

Describe your decision making process under risk and/or uncertainty? Do you use subjective probabilities in assessing the magnitude of risk?

To what extent are the important decision makers in your company comfortable with probability assessments? Are they familiar with Utility Theory? Multiattribute Utility Theory? AHP?

What are your feelings towards those decision making tools? Does your company use the computer to help decision making under risk? If so, in what capacity?

If risk assessment techniques are used, how much do you think they actually cost? Do the benefits outweigh these costs?

How is it possible to compare the performance with and without more formal decision making tools under risk? Is there a significant difference? Is it possible to get old data, use some decision making tools under risk, make a new decision, and compare results to what actually occurred?

These are some of the questions which may be asked in a survey. However, the questionnaire should be designed so that the data can easily be analyzed by different multivariate statistical techniques. It can be hypothesized that different industries have different definitions about risk. These definitions will belong to the number of risk definitions found in this literature search. Furthermore, it may be hypothesized that companies with more formal decision making procedures in the same industry tend to understand risk and its implications better. Is there really a big gap between what we develop in academics and how much of it is actually used in practice?

Conclusion

There is a wealth of information about decision making under risk and risk assessment. Risk can be defined in several ways, depending on the context of the decisions to be made. It is generally expressed through the use of probability assessments and subjective judgments. This is evident when expert assessments are coded into probabilities in different ways. However, there is no comprehensive study on how widespread the application of techniques are in the real world. Furthermore, no attempt has been made to compare the use of these techniques among different industries.

REFERENCES

Aczel, J. & Saaty, T.L., "Procedures for Synthesizing Ratio Judgments", Journal of Mathematical Psychology, 1983, 27, 93-102.

"The requirements of for functions synthesizing judgments of separability, associativity, cancellativity, consensus, and homogeneity properties are investigated. All the functions satisfying them are investigated."

Aczel, J. & Alsina, C., "On Synthesis of Judgments", Socio-Econ. Plann. Sci., 1986, 20, 6, 333-339.

"Synthesizing judgments is an important part of the analytic hierarchy process (AHP)." Additional information or debates may change the initial quantified judgments of several individuals. After all information have been considered and all efforts to change some of the participant's opinions have been done, either there is a consensus or there are still judgments to be synthesized. This article uses Saaty's simple geometric mean as a synthesizing function.

Aczel, J. & Alsina, C., "Synthesizing Judgments: A Functional Equations Approach", Math Modelling, 1987, 9, 3-5, 311-320.

After several individuals have given their quantitative assessments about either a measure of an object or a ratio of these measures, there can be two outcomes. Either there is consensus about the evaluations, or there are still different judgments which have to be "synthesized". This can be accomplished by "a further systematic procedure bringing consensus among the individuals or by an external decision maker who consults the group, or a combination of both". This study builds on Saaty's use of the geometric mean as a synthesizing function. The article is primarily an in-depth mathematical approach to identify the synthesizing function or a family of functions which contain the geometric mean.

Baird, I.S. & Thomas, H., "Toward a Contingency Model of Strategic Risk Taking, Academy of Management Review, 1985, 10(2), 230-242.

"A model of strategic risk incorporating environmental, industrial, organizational, decision maker, and problem variables is presented." The model of strategic risk taking developed intent is to stimulate research geared towards an understanding of the relationships between factors internal and external to a firm. This study emphasizes the need for more studies about the definition of strategic risk and more understanding about the concept as applied to strategy and other business topics.

Borcherding, K., Eppel, T. & Von Winterfeldt, "Comparison of Weighting Judgments in Multiattribute Utility Measurement, Management Science, December 1991, 37(12), 1603-1619.

Four weighting methods in multiattribute utility measurement are compared with respect to their internal consistency, convergent validity, and external validity. The four methods were the ratio method, the swing weighting method, the tradeoff method, and the pricing out method. "Two hundred subjects used these methods in weighting attributes for evaluating nuclear repository sites in the US." It is recommended in applications "to improve the internal consistency of the tradeoff method and by careful interactive elicitation and use it in conjunction with the pricing out method to enhance its external validity."

Bourgeois, III, L.J., "Strategy & Environment: A Conceptual Integration", Academy of Management Review, Spring 1980, 17-31.

"Strategy has the two primary purposes of defining the segment of the environment in which the organization will operate." This article then defines a hierarchial definition of strategy: domain definition, and domain navigation. On the other hand, the environment is subdivided into its objective and perceived states. It is then argued that "the concepts of strategy and environment are integrated in that the primary strategy concerns opportunities in the general environment and the secondary strategy involves navigating within the task environment."

Bowman, E. H., "A Risk Return Paradox for Strategic Management", Sloan Management Review, Spring 1980, 17-31.

The paper explores the relationships among risk, uncertainty, and profit which has been attracting academics for quite some time. Previous studies carries the impression that higher-risk projects or investments must carry with it higher expected returns in order to be undertaken by risk-averse managers. This paper gives us reasons to doubt the positive association between risk and return. The findings indicate that for majority of the industries studied, "higher-average-profit companies tended to have lower risk, i.e., variance over time".

Collins J.M. & Ruefli, T.W., "Strategic Risk: An Ordinal Approach", Management Science, 1992, 38(12), 1707-1731.

This paper proposes a new measure of risk , a measure based on the chance of loss of relative position within a group of firms. The chance of loss, the degree of probability of loss, and the amount of probable loss are all considered. Transition matrices and a measure of system risk based on entropy theory are used to address possible rank changes.

Conrath, D.W., "From Statistical Decision Theory to Practice: Some Problems with the Transition", Management Science, April 1973, 19(8), 873-883.

Numerous statistical decision models have been developed, but little attention have been given to applying them in the "real world". This paper approaches one aspect of the conversion process: the conceptualization and use of probabilistic data for decision-making. Three final observations were worth reporting. "First, decision-makers have difficulty conceiving probability distributions; they are more comfortable with point estimates. Secondly, The concept of "risk of failure" or the probability of failing to meet a perceived target affects the choice. Thirdly, choice behavior is affected by the format with which probabilistic data is presented." Finally, a simple descriptive model of decision making under risk was developed.

Cooper, A.C. & Schendel, D., "Strategic Responses to Technological Threats", Business Horizons, February 1976, 19(1), 61-69.

Several established industries are threatened by major technological innovations. Based on these threats, industries must appraise the impact of these technological innovations and decide on which response strategies to undertake. They may do nothing, participate in the new technology, or continue and improve the old technology. Different levels of participation and commitment to the chosen response are briefly discussed.

Dennis, S.Y., "A Probabilistic Model for the Assignment of Priorities in Hierarchically Structured Decision Problems", Math Modelling, 1987, 9, 3-5, 335-343.

The purpose of this paper is to extend the investigation of a probabilistic approach to modelling uncertainty in the eigenvector scaling process. "An approach to analyzing the assignment of priorities under uncertainty in hierarchically structured multicriterion decision problems is developed using the principle of hierarchical composition." Their results indicate that "the analysis of uncertainty in complex decision problems is distributionally invariant to the complexity of the associated hierarchy."

Eckenrode, R.T., "Weighting Multiple Criteria", Management Science, Nov 1965, 12(3), 180-192.

This research's primary concern was to identify efficient and reliable methods for collecting data on human judgments of relative value of a list of items. "Six methods for collecting the judgments of experts concerning the relative value of sets of criteria were compared for reliability and time efficiency. These were ranking, rating, three versions of paired comparisons, and successive comparison. The results show that there were no significant differences in the sets of criterion weights derived from collecting the judgment data by any of the methods. Ranking was determined to be by far the most efficient method."

Eliasberg, J., "A Methodology for Group Decision-Making Under Uncertainty", D.B.A. Dissertation, 1977, Indiana University.

A group decision making under uncertainty wherein a decision is made, either by the group collectively or by a supra decision maker is considered. It is assumed that the payoff from the decision can be divisible. The study proposes a normative methodology to deal with this situation. "The methodology is utilized to study both additive and multilinear forms of multiattribute utility functions." Results show that some families of utility functions adequately describe the preferences of a large number of decision makers.

Emmelhainz, L.W., "Influence of Risk and Uncertainty on Logistics Decision Making: An Experiment", 1986, PhD. Dissertation, Ohio State University.

"The main objective of the research was to determine the influence of risk and uncertainty on logistics decision making. Using the basic concepts of prospect theory, the research extended the theory in an attempt to explain decision making under realistic business conditions. The research showed that the objective given to the decision maker interacted with cost, cost uncertainty, and service uncertainty to influence the evaluation of the cost-service tradeoff."

Farquhar, P.H., "Utility Assessment Methods", Management Science, Nov. 1984, 30(11), 1283-1300.

"This paper is a comprehensive study of methods for assessing unidimentional expected utility functions. The utility assessment process in decision analysis is described, followed by a review of problem formulation, sources of bias in preference judgment, and the analysis of risk attitudes. These methods are grouped into preference comparison methods, probability equivalence methods, certainty equivalence methods, hybrid methods, paired-gamble methods, and other approaches." Additionally, a dozen new utility assessment models are critically examined.

Fellner, W., "Distortion of Subjective Probabilities as a Reaction to Uncertainty", Quarterly Journal of Economics, 1961, 75, 670-690.

Fishburn, P.C., "Foundations of Risk Measurement. I. Risk as Probable Loss", Management Science, 1984, 30(4), 396-406.

The main thrust of this paper is to address risk measurement from an axiomatic perspective. Proposed conditions on a relation "is at least as risky as" between pairs of probability distributions over an outcome variable are presented. This article is both very theoretical and mathematical.

Fishburn, P.C., "Foundations of Risk Measurement. II. Effects of Gains on Risk", Journal of Mathematical Psychology, 1982, 25, 226-242.

This is a continuation of Fishburn's previous article on risk measurement. This part discusses "measures of risk that include effects of gains on perceived risks". It is argued that increased "gains can reduce the risk of fixed probable loses without completely negating that risk", and that prospects which do not have a chance of a loss are considered to have nor risk.

Friar, S. A., "Decision Making Under Risk: An Experimental Study Within a Business Context", PhD. Dissertation, University of Texas at Austin.

"Accountants play a vital role in determining what type of information they make available to the decision makers. Specification of the type of information depends in part to the environment, the context of the decision, the complexity of the task, and an understanding of how the decision makers perceive the task environment. The following aspects of decision making were investigated in a laboratory experiment: (1) the effects of two types of risk information on decision making, the effects of aspiration level on decision making, (3) the applicability of a simple breakeven model in decision making and (4) the effects of realized outcome on subsequent decisions."

Fry, P. C., "A Comparison of four multiattribute utility function elicitation procedures for preference predictions", PhD. Dissertation, 1988, The Louisiana State University and Mechanical Col.

The purpose of this study was to investigate the predictive ability of four multiattribute elicitation procedures. These are: Keeney-Raiffa (KR), holistic orthogonal parameter estimation (HOPE), simple multiattribute rating technique (SMART), and mathematical programming. They were judged in terms of ordinal preference predictions, first preference predictions, and their ability to capture tradeoffs between competing objectives. This research provides an initial set of guidelines to choose among different MAUF elicitation techniques.

Greer, Jr., W.R., "Theory Versus Practice in Risk Analysis: An Empirical Study", The Accounting Review, July 1974, 496-505.

This article hypothesizes that there is a basic conflict between utility theory and actual risk-tolerance decision processes. It is asserted that the lack of practitioner interest in the use of utility theory is due to the failure of utility theory to synthesize the decision process. Classical utility theory is "unable to deal effectively situations where one or more contingent outcomes for a project are lower than some critical value." This inability is due to the tendency of decision makers to be more risk averse at the time of actual choice than what his or her pre-decision statements suggest.

Hammond III, J.S., "Simplifying the Choice Between Uncertain Prospects Where Preference is Nonlinear", Management Science, March 1974, 20(7), 1047-1072.

Two practical difficulties in using preference or utility theory are addressed. "These are assessing the preference curve and doing the calculations with the resulting curve which may not have an analytically-convenient functional form." The requirement that all major decisions and uncertainties be encompassed in the same analysis is another difficulty which is not covered in this article. These difficulties make utility theory see relatively little use in actual business decision-making. Identifying circumstances under which simplifications that overcome these difficulties while also properly reflecting the attitude towards risk will be very helpful. It is shown that it is often possible to make decisions with only rough knowledge of the decision maker's preference curve by using a substitute curve. The study also provided areas for future investigation: assessing a bound on a decision-maker's risk, and determining how strictly the assumptions must hold.

Huber, G.P., "Methods for Quantifying Subjective Probabilities and Multi-Attribute Utilities", Decision Science, 1974, 5, 430-458.

"In many situations where normative decision-aiding techniques could be usefully applied, historical data are inadequate for estimating the required outcome probabilities. Economic methodologies are inadequate for estimating the aggregate utility derived from the several outcome attributes. Hence, it is often useful to obtain the required estimates in the form of expert judgments. Methods for eliciting subjective probabilities and multi-attribute utilities are described. Summary guidelines concerning the elicitation of and use of expert judgments are also included."

Jemison, D.B., "Organizational versus Environmental Sources of Influence in Strategic Decision Making", Strategic Management Journal, 1981, 2, 77-89.

"This paper reports the results of a field study that explored the relative impact of environmental interactions and internal organizational activities on interorganizational influence on strategic decision making." The technology of the organization affects the environmentally and internally derived sources of influence on strategic decision making. Position power is still the most important type of power as far as strategic decision is concerned.

Jemison, D.B., "Risk and Relationship among Strategy, Organizational Process, And Performance", Management Science, Sept. 1987, 33(9), 1086-1101.

Strategy content, organizational processes, risk and return are studied in this article at the business strategy level. Previous studies showed that risk and return are negatively correlated. Several hypothesis are postulated in this paper, one of which considers risk as a dimension of performance in the business-level strategy. Their study showed that organizational strategy is related to both risk and return; processes that varied with return were different from those that varied with risk. Hence, risk and return should both be considered in performance evaluations.

Kahneman, D. & Tversky, A., "Prospect Theory: An Analysis of Decision Under Risk", Econometrica, 47: 263-291.

This paper critiques the expected utility theory as a descriptive model of decision making under risk and proposed an alternative "prospect theory". The author shows that people overweigh outcomes
that are considered certain relative to outcomes which are probable. He labels this the "certainty effect". Another observation is the "isolation effect" which occurs when people generally discard components that are shared by all prospects under consideration. This may lead to different preferences. These two problems are considered in this proposed prospect model. (long article).

Keeney, R. L., von Winterfeldt, D., "On the Uses of Expert Judgment on Complex Technical Problems", IEEE Transactions on Engineering Management, May 1989, 36, 2, 83-86.

"The role and uses of expert judgment in examining complex technical and engineering problems are discussed. The article demonstrates how expert judgments are used in analyzing technical problems, how to improve the use of expert judgments, and how to interpret expert judgments in analysis. The value of quantifying expert judgments in analysis are stressed. The relationships between procedures to quantify judgments are also discussed."

Keeney, R.L., von Winterfeldt, D., "Eliciting Probabilities from Experts in Complex Technical Problems", IEEE Transactions on Engineering Management, Aug 1991, 38, 3, 191-201.

"Expert judgment is used throughout all technical analysis of complex problems. There has been an increase in the need for defensibility and accountability of these expert judgments. Increased scrutiny and review of the expert judgments used as a result of the increase in the need for defensibility and accountability of these analyses. Two formal elicitation processes were used to obtain probabilities from experts in a large-scale study involving nuclear safety. A comprehensive process to elicit probability judgments is outlined in detail."

King, R. P., "Operational Techniques for Applied Decision Analysis Under Uncertainty", 1979, PhD. Dissertation, Michigan State University.

Several techniques in this study were designed for use in the four phases of an applied decision analysis, namely, problem formulation, determination of subjective probability distributions, measurement of decision maker preferences, and the identification of the preferred choices. "When taken together, they represent an integrated set of techniques which facilitate the application of decision theory based on expected utility hypothesis." A new approach which permits the construction of interval measurements of a decision maker's absolute risk aversion is presented.

Lambert, D. K., "Risk Modelling using Direct Solution of Expected utility Maximization Problems", PhD. Dissertation, 1985, Oregon State University.

"A model of agricultural decision making where the expected value of utility evaluated under alternative outcomes is directly maximized in a non-linear programming model. It had two features distinguishing it from traditional risk programming models: First, alternative attitudes toward the assumption of risk are implicitly specified by the choice of the utility function. Second, the empirical distribution of the uncertainty parameters directly enter the model, avoiding assumptions regarding the parameters distributional form."

Leland, J. W., "Individual Choice Under Uncertainty: Finite Discriminatory Ability and Systematic Deviations from "Strict" Rationality, PhD. Dissertation, 1986, University of California, Los Angeles.

"This dissertation proposes that people fail to obey the axioms and assumptions of the expected utility hypothesis due to their limited ability to accurately and consistently assign utility and probability values to the components of risk prospects". He proposes an "approximate utility model" in which "the notion of limited ability to evaluate prospect components is explicitly incorporated as a constraint upon the agent's ability to maximize his expected utility in every choice situation".

Libby, R. & Fishburn, P.C., "Behavioral Models of Risk Taking in Business Decisions: A Survey and Evaluation", Journal of Accounting, 1977, 15, 272-292.

"Risk taking in business situations can be described by a variety of models. This paper provides a classification of structure for alternative models of risky choice and a review of their ability to predict actual business behavior." This article is organized into four sections: classification scheme of alternative risky choice, a review of the empirical evidence concerning the validity of those models as predictors of actual business decision behavior, situational differences in risk-taking behavior, and the summary of the results and conclusion.

March. J.G. & Shapira, Z., "Managerial Perspectives on Risk and Risk Taking", Management Science, Nov 1987, 33(11), 1404-1418.

"This paper explores the relations between decision theoretic conceptions of risk and the conceptions held by executives." The study showed that managers take risk and exhibit risk preferences, but the processes that they go through are quite different from the classical processes of choosing among alternatives in terms of the mean and variance of the distributions over possible outcomes. Managers are quite insensitive to estimates of the probabilities of possible outcomes; they make a sharp distinction between risk and gambling. Lastly, their decisions are affected by the way their affection is focused on critical performance targets. All these indicate that a study of risk taking in organizational settings will be imperfectly understood within a classical conception of risk.

Miller, K.D., & Bromiley, P., "Strategic Risk and Corporate Performance: An Analysis of Alternative Risk Measures", Academy of Management Journal, Dec. 1990, 33(4), 756-779.

"Various measures of corporate risk strategic management research reflect different risk factors. A factor analysis of nine measures of risk showed three factors: income stream risk, stock returns risk, and strategic risk." The study looked at the influences of risk on corporate performance, and corporate performance on risk.
The study indicate that high or good performance reduces subsequent income stream uncertainty while low performance increased income stream risk.

Mintzberg,H., Raisinghani, D. & Theoret, A., "The Structure of "Unstructured" Decision Processes", Administrative Science Quarterly, 1976, 21, 246-275.

"A field study of 25 strategic decision processes, together with a review of related empirical literature, suggests that a basic structure underlies these "unstructured processes". The structure is described in terms of 12 elements: 3 central phases, 3 sets of supporting routines, and 6 sets of dynamic factors. This paper discusses each of these elements and proposes a general model to describe the interrelationships among them. The 25 strategic decision processes studied are then shown to fall into 7 types of path configurations throughout the model."

Morris, P.A., "Combining Expert Judgments: A Bayesian Approach", Management Science, March 1977, 23(7), 679-693.

A Bayesian inferential framework based approach is used to provide a mechanism by which a decision maker can incorporate the possibly conflicting probability assessments of a group of experts. Both one and multiple expert situations are considered. "In the single expert continuous variable case, the decision maker should process a calibrated expert's opinion by multiplying the expert's probability assessment by his own probability assessment and normalizing. In the multi-expert case, there exist a composite probability function which measures the joint information contained in the probability assessments generated by a panel of experts."

Ravenscraft, D. & Scherer, F.M., "The lag structure of returns to research and development", Applied Economics, 1982, 14, 603-620.

R&D is perhaps the most important contributor to technological progress and productivity growth. "Time is a critical variable in measuring returns to R&D; it takes about three years on the average to complete an R&D project." The authors used rich micro-data and powerful econometric techniques to gain insights into the lagged effect of industrial R&D (1970's) on profitability. The study showed that the lag structure is roughly bell-shaped, with a mean lag of four to six years. It seemed that competition was so vigorous in more technologically dynamic markets that the profits from innovation tended to be eroded quickly.

Russell, A.D. & Ranasinghe, M., "Analytic approach for economic risk quantification of large engineering projects", Construction Management and Economics, July 1992, 10(4), 277-301.

This paper aims to quantify uncertainty of a derived variable by creating a cumulative distribution function for that variable. Uncertainty and risk are defined to be synonymous. "The goal is to produce a computationally efficient tool that can be used to explore economic feasibility and tradeoffs between cost and time performance versus risk as a function of various strategies for executing and sequencing major work packages." Their approach applies a risk measurement framework based on moment analysis.

Saaty, T.L. & Vargas, L.G., "Uncertainty and rank order in the analytic hierarchy process", European Journal of Operational Research, 1987, 32, 107-117.

The concern of this paper is the uncertainty about the range of judgments used to express preferences. AHP was used via paired comparisons to derive a scale of relative importance, which is then used to ranking several alternatives. "The uncertainty experienced by decision makers in making comparisons is measured by associating with each judgment an interval of numeric values." The probability that an alternative or project will change ranks with competing alternatives or projects is derived and used to calculate the probability that the project will actually change rank. Final rankings are established after the priority of each alternative or project are considered.

Scherer, F. M., "Research and Development Resource Allocation Under Rivalry", The Quarterly Journal of Economics, August 1967, 81, 3, 359-394.

This paper makes an attempt to "analyze the phenomenon of research and development rivalry in a dynamic maximization framework, and to predict market structural conditions most conducive to rapid technological progress". "Revenues from successful completion of R&D projects depend on the time of completion, the quality of the end product, and the reaction of rivals, while the costs depend on the state of technology, the quality of the end product, and the speed of development". The article goes in detail to discuss the rivalry problem, duopoly market structures, technological vigor, and the n-firm problem.

Schoemaker, P.J.H. & Waid, C.C., "An Experimental Comparison of Different Approaches to Determining Weights in Additive Utility Models", Management Science, Feb 1982, 28(2), 182-196.

Five conceptually different approaches used in determining weights in additive utility models were evaluated in terms of their weights and predictive ability. "These are: multiple linear and non-linear regression analysis of ten and fifteen holistic assessments, direct decomposed tradeoffs as proposed by Keeney and Raiffa, an eigenvector technique of Saaty involving redundant pairwise comparisons of attributes, a straightforward allocation of hundred importance points,

and unit weighting." The methods generally differed systematically concerning the weights given to the various attributes and the variances of the resulting predictions. "The methods predicted equally well on the average, except for unit weighting which was clearly inferior. Nonlinear methods were found to be inferior to linear ones. Subjects viewed the methods to differ significantly in difficulty and trustworthiness." These correlated inversely.

Shah, K. & LaPlaca, P.J., "Assessing Risk in Strategic Planning", Industrial Marketing Management, April 2, 1981, 10, 77-91.

A method for analyzing marketing, competitive, financial, business portfolio, technological, and regulatory risks is presented. While the emphasis of the article is the assessment of marketing risks, the other types of risks are also discussed. The authors outlined a brief recipe for a marketing strategic risk assessment: "identify risk elements, assess the impact of each risk event, develop supportive probabilities for the occurrence of each risk, prepare alternative strategies and contingency plans for important risk events, and keep looking for other risks."

Shira, Z., "Behavior under uncertainty: The decision criterion, the attitude toward risk, and the choice of labor supply", PhD. Dissertation, 1989, University of California, Berkeley.

This dissertation is divided into three studies: "the nonparametric test of the expected utility hypothesis, the econometric estimation of farmers' risk aversion, and the behavior of farmers' labor supply". In the second part, it is shown that the expected utility hypothesis holds if there exist a feasible solution to a system of linear inequalities. If this is the case, then the system of linear inequalities can be manipulated to yield boundaries on the coefficient of absolute risk aversion. The third part provided an opportunity to test Arrow's hypothesis of decreasing absolute risk aversion and increasing relative risk aversion.

Singh, J., "Perfromance, Slack, and Risk Taking in Organizational Decision Making, Academy of Management Journal, 1986, 29(3), 562-585.

"This paper investigates the relationship between organizational performance and risk taking in organizational decision making." The theoretical model proposed supported the hypothesis that there is a negative direct relationship between performance and risk taking. Covariance structural modelling was used to better understand organizational responses to decline, organizational innovation, and risk and return through the use of direct and indirect relationships among the variables.

Sjoberg, L., "The Risks of Risk Analysis", Acta Psychologica, 1980, 45, 301-321.

This article explores the results of using risk analysis as tool used in assessing risky technologies. It discusses the purposes and limitations of risk analysis. Risk debates are examined with respect to conditions, information, and structure. It is concluded that risk

analysis can contribute to decision making if its values and limitations are taken into consideration.. However, it may be difficult to use in assessing technology risks because it is highly provocative.

Spetzler, C.S. & Von Holstein, C.S., "Probability Encoding in Decision Analysis", Management Science, Nov 1975, 22(3), 340-358.

A summary of the probability encoding methods used by the Decision Analysis Group at Stanford Research Institute is presented in this article. It was emphasized that the procedures used for a particular uncertain quantity always depended on the quantity and its importance for a decision, the subject, and the interviewer. Their approach can be distinguished by the pre-encoding steps, the use of only ordinal judgments, the use of a reference process (such as the probability wheel), and the use of more than one technique for use as a consistency check in both encoding and verifying steps. The authors recommend a structured interview process conducted by a trained interviewer. A number of techniques designed to reduce biases and aid in the quantification of judgment is used.

Souder, W.E. & Bethay, D., "The Risk Pyramid for New Product Development: An Application to Complex Aerospace Hardware, Journal of Product Innovation Management, June 1993, 10(3), 181-194.

This article develops a risk-pyramid which puts technical risk, market risk, and business risk as sides of the triangle, with benefits, technology, and form comprising the bases. The center of gravity of the pyramid is labelled "center of risk". The configuration of the triangle will change, depending of the interaction of the bases and the sides. Consequently, the center of risk will also move. This center of risk can be looked upon as a way of measuring the potential for product failure. If the center of risk moves upward as a result of risk-product trade-offs, then there is greater likelihood of eventual product failure.

Tversky, A. & Kahneman, D., "Judgment Under Uncertainty: Heuristics and Biases", Science, Sept. 1984, 185, 1124-1131.

"This article described three heuristics that are employed in making judgments under uncertainty. Representativeness is employed when people are asked to judge the probability that an object or event A belongs to class or process B. Availability of instances or scenarios is employed when people are asked to assess the frequency of a class. Adjustment from an anchor is usually employed in numerical prediction when a relevant value is available. Although these heuristics are highly economical and usually effective, they lead to systematic and predictable errors. A better understanding of these heuristics and of the bias to which they lead could improve judgment and decisions in situations of uncertainty."

Tversky, A., Slovic, P., & Sattath, S., "Contingent Weighting in Judgment and Choice",

Psychological Review, 1988, 95, 371-384.

"Preference can be inferred from direct choice between options or from a matching procedure in which the decision maker adjusts one option to match another. Studies of preference between two-dimensional options indicate that more prominent dimensions loom s larger in choice than in matching. The weighting of inputs is enhanced by their compatibility with the output." The authors develop a 'contingent weighting model' in which the trade-off between attributes is contingent on the nature of the response.

Vlek, C. & Stallen, PJ., "Rational and Personal Aspects of Risk", Acta Psychologica, 1980, 45, 273-300.

This article answers some key questions oh how risk may be defined. Various possible human reactions to risky situations are discussed. Finally, seven categories of fundamental aspects of risky decisions are considered in relation to each other. These are: voluntariness of exposure, controllability of consequences, distribution of consequences in time, distribution of consequences in space, context of probability assessment, context of accidental evaluation, and combination of accident-probability, and seriousness.

Wallsten, T.S. & Budescu, D.V., "Encoding Subjective Probabilities: A Psychological and Psychometric Review", Management Science, Feb 1983, 29(2), 151-173.

A general framework for evaluating and assessing subjective probability encoding can be obtained from well-established concepts and theories from measurement and psychometric theory. Studies on subjective probability encoding can be classified into studies conducted with experts and studies conducted with nonexperts. "There are five major classes of studies which provide as reasonable framework for summarizing a large body of results: reliability, internal consistency, calibration, external validity, and construct and inter-response correlation validity." Of these classes, the biggest difference between experts and nonexperts in the calibration (If a probability encoding technique correlates well, and is related by an identity transformation to an independently obtained measure of probability, then it is said to be "calibrated".). Experts can be exceedingly well-calibrated when encoding subjective probabilities about events that they are familiar with.

Wedley, W., "Combining Qualitative and Quantitative Factors-An Analytic Hierarchy Approach", Socio-Econ. Plann. Sci., 1990, 24, 1, 57-64.

"The Analytic Hierarchy Process provides a general theory of measurement for expressing both tangible and intangible factors." In this study, the authors looked upon these intangible or qualitative factors as measures which they have not learned to use very well. They used AHP to handle complex problems, utilizing the technique in three required steps: "decomposition of the problem into a hierarchy of components or elements, determination of ratio weights or priorities for the elements of the hierarchy, and composition of those numbers into overall weights which measure the decision outcomes". Some difficulties using AHP were discussed.

Overall, it is argued that AHPs ability to structure and analyze make it successful as a decision-making tool.

Woo, C.Y., "Path Analysis of the Relationship Between Market Share, Business-Level Conduct and Risk, Strategic Management Journal, 1987, 8, 149-168.

The main hypothesis of the article is that market share reduces business level risk. However, the study only offered qualified support to the risk-reduction effects of market share. However, this model included the use of path-analysis which provides for the decomposition of total effects into direct, indirect, and spurious effects.

Note: This annotated bibliography was complied to help determine possible research areas in risk analysis and measurement. Because of the brevity of the description of each article, it is often very difficult to express the author's ideas without quoting directly or almost directly from the article itself or the published abstract (mostly PhD. dissertations). If the words were quoted exactly or almost exactly, quotes were used. However, the ideas contained in this annotated bibliograpy are the author's and I tried to get the most important messages as they relate to my intention.