Fall 2007

Cognitive biases in risk management

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COGNITIVE BIASES

IN

RISK MANAGEMENT

by

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A THESIS

Presented to the Faculty of the Graduate School of the

UNIVERSITY OF MISSOURI-ROLLA

In Partial Fulfillment of the Requirements for the Degree

MASTER OF SCIENCE IN SYSTEMS ENGINEERING

2007

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ABSTRACT

The purpose of this thesis is to explore the relationship of risk management/mitigation and the people who practice the discipline. Much has been written concerning risk and the analytical ways that it can be measured. The need for accurate and timely risk mitigation has accelerated with the pace of new and replacement programs. A part of the process that needs to be updated is that risk needs to be seen as systems attribute, much the same as cost, schedule and technical compliance.

It is absolutely necessary that today's Systems Engineers develop and follow a Risk Management and Mitigation Plan in the early phases of the project. It is also important that the appropriate Risk Management/Mitigation process be selected.

This thesis contends that most Risk Management/Mitigation programs fail to be as effective as they could be due to a number of mostly overlooked drivers, such as motivation and cognitive biases. The issue of cognitive biases is very seldom addressed. When questioned, most engineers purport to not have any biases. They insist that they use only logic, reasoning, and math to make decisions.

A set of data was collected and reviewed for this thesis. The data presented shows that cognitive biases do affect the risk management/mitigation process. Knowledge of these biases and their potential impact on a project will lead to better risk management.

ACKNOWLEDGEMENTS

I wish to acknowledge the invaluable assistance given me by Dr. Eric Smith during the creation of this thesis. His guidance and knowledge were always positive and available when needed. His support and continue pushing allowed me to create a body of work that I can be proud of.

My advisor Dr. Cihan Dagli never lost sight of the ultimate goal, to create a body of work that I could be proud of. He was always available when I needed his guidance and provided the goals I needed at the start of the journey.

I would like to acknowledge all of the help and encouragement I received from my friends and co-workers during this process. There are too many people to name specifically, so I merely say “Thank You” to all who supported me.

Lastly I wish to say to my wife Brenda, that I appreciate your support. I would not have been able to complete the process without your love and belief.

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1. INTRODUCTION

1.1 BACKGROUND

Risk Management and Mitigation have become extremely important and widely used in modern Systems Engineering. The need for accurate and timely risk mitigation has accelerated with the pace of new and replacement programs. Since the 1990s the time to market has been compressed at an extremely rapid pace, with the consequence that the effects of a realized risk are both more serious and much more difficult to overcome.

One example of the accelerating pace of new programs is in the military arena. In the 1970s three to four years was the norm for medium sized projects and major projects could last a decade. Today, medium sized projects usually have a two to three year time to production. This compression is also felt in major projects. Projects that in the 1970s would have taken a decade are now completed in two to three years. The commercial world has compressed schedules even further; projects that today take six months would have taken eighteen months a decade ago.

Keeping modern requirements in mind, it is absolutely necessary that today's Systems Engineers develop and follow a Risk Management and Mitigation Plan in the early phases of the project. It is also important that the appropriate Risk Management/Mitigation process be selected. For example, a process used by NASA for the Mars Rover program is probably too complex for the development of a single piece of electronics. Although it is true that risk management is a universal program/project requirement, the approach taken should not be “one size fits all.” A system that is not appropriate for the task at hand should not be used.

This thesis contends that most Risk Management/Mitigation programs fail to be as effective as they could be due to a number of mostly overlooked drivers, such as motivation and cognitive biases. It is the author’s assertion that most risk programs are less effective than they could be due to resistance from both engineers and program managers. Two basic examples of this type of passive resistance are:

1) Many engineers do not want to admit that there are any risks associated with the project [Kasperson and Kasperson, 1996].

2) Many program managers do not want to present negative aspects of their program to higher management or the customer [Kasperson and Kasperson, 1996].

In the first case, many engineers do not see the need for a risk management program. They feel that they are dealing with the risks on a day-to-day basis and do not need any interference from management in doing their job. Others feel that showing a risk reflects badly on the engineers’ ability to design and deliver a compliant artifact. In any case the tendency of human nature is to deny and hide that which makes one look bad.

In the second case, management has a responsibility to foster a culture of openness which includes not “shooting the messenger” in the case of perceived bad news. Management also needs to work with its customers so that both have the same approach to risk. The customer needs to work as a part of the “team” to help mitigate risks at all stages of the project.

It is not an accepted fact that risk is an attribute of the systems architecture in the same way as cost, schedule, and performance. Once management begins treating risk as a system attribute the process of risk management will enter a new era. [Dagli, 2007]

Figure 1.1 illustrates Risk as a Systems Attribute. The central premise is that risks are hidden when it is possible to do so. Given that risk is a negative attribute of the system and that the general tendency is to hide risks [Kasperson and Kasperson, 1996], a system to help disclose risks is necessary. The approach shown in Figure 1.1 offers a path to follow for the acceptance of Risk as a Systems Attribute.

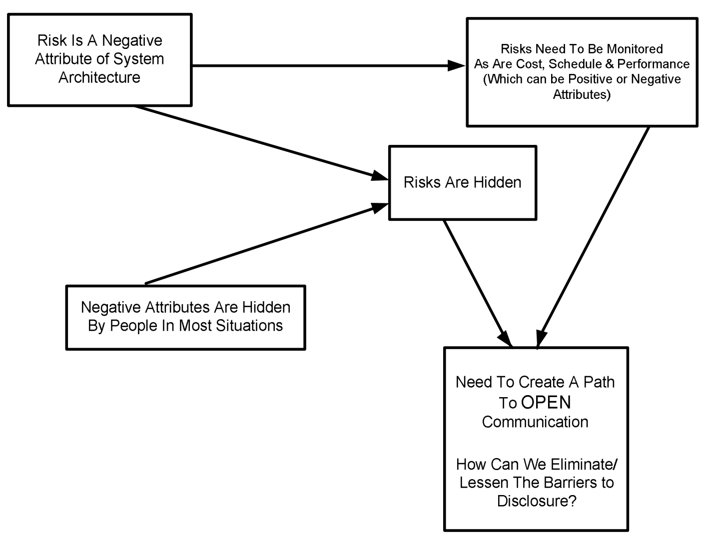

Figure 1.1 Risk as a systems attribute

1.2 MOTIVATION

The motivation for risk management/mitigation is multifaceted. Current industry trends prescribe addressing and eliminating most, if not all, risks to a project. While this is an admirable goal, it is not generally achievable in the real world. However, this admirable goal keeps driving the development of risk management/mitigation.

The goal of this thesis was to determine if there are any practical methods in use in the military/aerospace industry that address the psychological aspects of risk management. For instance, when management decrees that there will be “risk management/mitigation” for all programs, what subjective or psychological perceptions interfere with the process? Is risk management/mitigation really practiced? Is it effective?

The psychological pieces of risk management are not well understood by most engineers and engineering managers and, thus, are not handled properly by most risk programs. In fact, the psychological aspect of risk management is generally not addressed at all [Saad and Hsu, 2003], [Snyder and Buede, 2000] and [Gilb, 2002]. Each of the studies cited above are excellent examples of the technical and analytical approach to risk management, but none addresses the psychological aspects of the process.

The issue of cognitive biases is very seldom addressed. When questioned, most engineers purport to not have any biases. They insist that they use only logic, reasoning, and mathematics to make decisions. This is, of course, not true at all. All people are influenced by outside forces and factors such as education, culture, corporate culture, and experience. Another such area of influence is cognitive bias. Cognitive Biases occur despite the subject's intent to obtain the correct answer or the predisposition towards a particular solution or path in any given set of circumstances.

Of the technical/engineering papers researched by the author, not one was devoted to the impact of human beings on the risk management process. All of these papers address technical issues and how to manage them, but none did more than make passing comments about the people involved in the process.

1.3 PROBLEM DEFINITION

The problem is not a simple one. Asking why people often resist the process of risk management leads to many more questions. Basic human nature tends to avoid that which makes us look bad, or is perceived as making us look bad.

Most people, engineers included, have learned that, in many situations, admitting even a perceived weakness means opening oneself up to criticism from both peers and management. The receiver of criticism often perceives it as punishment. There is a natural tendency to believe in oneself and to take criticism not intended as personal as an attack on the individual.

This bias of not admitting the possibility of having made an error or not knowing the correct course to follow is perhaps the most common one in industry. Many an engineer has forced data to fit a preconceived desirable outcome. Perhaps the most notable example is NASA and the Challenger launch decision, as illustrated by Vaughan. [Vaughan, 1996]

A certain amount of emotional involvement is necessary by most people; otherwise, progress is often not made in the project. The exact amount of emotion attached to any project will vary from person to person and among corporate cultures. This is true no matter what the project and no matter who the participants are. A sense of ownership is required to ensure that the project is completed on schedule and meets more than just the minimum requirements. It is not an act of serendipity that large corporations like Wal-Mart try to instill in their employees a sense of personal ownership in all of their tasks.

1.4 INTEGRATED PROCESS TEAMS

All members of the project team, including engineering, program management, company management, and the customer, must be a part of the process for it to provide the available results. It is important that risk management be addressed on more that just a “pro-forma” basis.

It has been the author’s experience that a positive team approach to risk management can and often does provide excellent results. Even when the results are not as positive as were hoped for, the fact that there was a real team effort minimizes negative impact on the team, including the customer.

It cannot be emphasized too strongly that everyone on the team must participate in the process of risk management. A pro-forma approach by any member of the team will often lower the likelihood of a successful outcome. The positive participation of both management and customers is vital to the health of the process.

Often, little attention is paid to risks until they become serious. Even companies with a reasonable risk management program suffer from this scenario. One example of this failure was a program that did not apply the Risk Management Program in place to a supplier. This supplier had a history of making leading edge products. The supplier was small and was dependent on one individual for the innovative designs that made their products leading edge. This dependence was well known at the company by both engineering and management, yet little attention was paid to the risk of being dependent on a single person. During a critical phase in a major project, the key individual became sick and was unable to complete the project.

What are risks and why are they important to a project? Risks are the areas in a project that are often unbounded by the scope or requirements of the project which can have a negative effect on its outcome. Being sometimes unbounded or fuzzy, they are often very hard to predict and can cause much damage to the project if not dealt with in the appropriate manner. This condition of uncertainty is true for all aspects of life and industry. No one wants to admit that what he or she did is anything less than what was required for the task. This condition holds true for engineers, program managers, janitors, and even CEO’s.

The culture of the organization has an impact on the way potentially negative information, including risk information, is handled. If the culture is punitive, with a “shoot the messenger mentality,” then employees will be less likely to disclose any negative information. If the culture is less punitive, employees will be more likely to disclose negative information. However, an open and non-punitive culture still does not guarantee that negative information will be disclosed.

One example is the company for which I currently work. There is little reason to hide potentially negative risk information. Still, however, many engineers and program managers only provide the barest information on risks and often present them in the most favorable light possible. A demonstrated managerial commitment to bi-directional risk management communication is required. Without this commitment people will not change their approach to risk disclosure.

The objective of this thesis is to make a case for change to both the engineering community and both engineering management and company management that will begin the process of better disclosure of risks. Once all parties begin the process of how risk viewed and see more the human part of the process begin to become more effective.

2. RISK LITERATURE REVIEW

2.1 RISK LITERATURE

A review of the literature on risk management/mitigation was undertaken in the area of human interaction and risk management and mitigation. During the research for this thesis no published, engineering oriented data was uncovered on the subject of human interactions and risk management. Examples of this lack of published data on the subject are the over twenty-five papers reviewed by the author from the International Council of System Engineering (INCOSE) library. Of the twenty-five papers reviewed, which span more than a decade, not one addressed the human interaction of risk directly.

Significant literature was found on the process of change management. The processes used to promote change in an organization are similar to those needed to promote the human issues in the risk management process. If people resist change, it follows that they will resist risk management unless risk management/mitigation is presented in a non-threatening manner and with the full support of management.

One commonly overlooked issue with risk management is of the problem of cultural inertia. Cultural inertia must be overcome with sustained attention to risk mitigation [Williams, 1978]. Newton's first law of motion is abstractly applicable to people and organizations.

2.2 RISK

Much has been written that addresses the technical aspects of risk management. Helm [Helm, 2004] addresses the issue of teaching students and engineers how to effectively create a risk statement, as well as the process of tracking mitigation a plan to completion. Helm does not address the underlying issue of why disclosure is important, other than to say it is important in order to make systems work.

The process of risk management must include human aspects in order to be as successful. When psychological aspects are left out, the risk management/mitigation process is incomplete. Most people working in a technical field do not consider the human part of the equation. Much time is spent devising ways to track and to measure both risk and mitigation efforts, but little or no effort is spent working to understand the human side of the process.

Real risk arises from both uncertainty (unknown relations and parameters) and known probabilistic relations. With what probability will an event happen and with what consequence? There are many terms used to express these dimensions. Likelihood or frequency of occurrence is often used in place of probability. The words consequence, severity, effect, and value are also often used interchangeably. Whatever terms you choose, an uncertain or probabilistic event with negative impact must be considered a risk. This relationship is shown in Table 2.1.

Table 2.1 Risk versus uncertainty

Uncertainty	No Probabilistic Distributions Are Known
Risk	Known Distributions

2.3 RISK DEFINITIONS

Risk Management: Risk management is all of the activities taken to identify, quantify and minimize risk to the project. This activity occurs at all phase of the project, not just engineering [Snyder and Buede, 2000].

Risk Mitigation: Risk Mitigation is process of attempting to minimize the impact of a risk to the program. Risk mitigation may include such activities as searching for new sources of supply, developing new technology or just assigning additional manpower to track and report on the status of the risk and its impact on the project.

Resistance to Change: Resistance to change is the natural human reaction to a new and potentially threatening circumstances. Fear of the unknown is one of the forces that cause many people to resist change. Inertia is also a major contributor to resistance. Why change when what we have produces known predictable results?

Cultural Inertia: Cultural Inertia must be overcome, whether through risk mitigation or change management. The analogy to Newton’s first law of motion applies even to people or organizations. Newton's first law of motion is often stated as: *An object at rest tends to stay at rest and an object in motion tends to stay in motion with the same speed and in the same direction unless acted upon by an unbalanced force.*

Feelings in Risk: Humans quickly and instinctively perceive negative circumstances. A common example is the human reaction to danger and the fight or flight decision that is made in real time [Slovic, Finucane, Peters and MacGregor, 2002].

Risk Mitigation as analysis: The engineering approach to problem solving is generally that of logic, reason, and a scientific approach to the problem. This approach is preferred by engineers and program managers because it is predictable and gives the appearance of being controllable. If you make a plan and follow the plan everyone is comfortable that you are doing the right things [Slovic, Finucane, Peters and MacGregor, 2002].

Politics in Risk: The clash between the real world and the perfect world most engineers would like to work in. A solution to a problem, no matter how elegant or appropriate, will not be implemented if it is not acceptable to all parties. If the customer or management does not like a solution the solution will not be implemented [Slovic, Finucane, Peters and MacGregor, 2002].

Schedule Risk: The potential negative impact to the schedule if the risk is realized. This is usually expressed in terms of a slippage or delay in the time it will take to complete the project.

Cost Risk: The potential impact to the project budget if the risk is realized. This is usually expressed in terms of dollars or man hours. Either method shows a potential increase in the cost of the project.

Technical Risk: The potential that the risk, if realized, will negatively impact the performance of the project. Often this type of risk receives the most attention although, in most cases, it is the least important type of risk. Lower technical performance will often be accepted in lieu of higher cost or a slip in schedule.

Risk Seeking: Risk seeking is observed in two classes of decision problems. First; overtly considering a small probability of winning a large prize over the expected value of the prize. Second; risk seeking is prevalent in the decision between a sure loss and a greater loss [Trevesky and Kahneman, 2004].

Loss aversion: Basic phenomena of choice under both risk and uncertainty; risk of loss is considered worse than prospect of gain [Trevesky and Kahneman, 2004].

2.4 RISK MANAGEMENT METHODOLOGIES

The primary method for the Architect to use is a structured tool or method for listing, and tracking the status of risks as a regular part of the project cycle. The tool selected should be appropriate to the type and scope of the project. Numerous tools are available, such as those shown by Gilb [Gilb, 2002]. The methods described by Snyder and Buede [Snyder and Buede, 2000], are appropriate for smaller projects with somewhat less complexity, while the method described by Gilb [Gilb, 2002] is more appropriate for larger, more complex projects. This thesis concerns the application of risk management to smaller projects or sub-sets of larger more complex projects.

Risk management to most people, including engineers and program managers, generally means an engineering problem. More than just an engineering problem, risk management/mitigation is a systems attribute in the same way as are cost, scheduling, and technical compliance. Until Risk is seen as a system attribute and pursued in the same manner as other attributes, risk management will be less effective than it could be.

An example of risks not always being considered an engineering issue is consideration of a perspective supplier's viability. Can the supplier meet the long-term requirements of the project? Is the supplier able to sustain himself financially for the life of the project?

During the early 1980s a major aerospace program experienced one example of this type of risk during the redesign of a power supply. The supplier chosen was qualified to manufacture the part required, but no attention was paid to its ability to sustain its business. The business base was not diverse enough to withstand the loss of its major customer. Once this major customer withdrew its business, the supplier was almost unable to continue to provide the required parts for the missile program. Had the program utilized an appropriate form of risk management during the development and supplier selection phase, the crisis would most likely have been avoided. Instead, the supplier almost stopped the program from delivering hardware. Only financial intervention by the program allowed the supplier to continue to deliver until another source could be developed.

It cannot be stressed enough that the tool selected be appropriate for the type of project being managed. In this case "one size fit all" can be a disaster. The use of a tool designed for a large project with a fairly long time line will not work well or even work at all on smaller projects with a short timeline. An example is the Space Shuttle; NASA has a time line of decades with multiple thousands of suppliers and different assemblies and parts. A tool used to track risks at the highest level of the project will not delve deep enough for some risks and for others will examine in too much detail. In either case, the misapplication of a tool will limit the effectiveness of the risk management process.

2.5 PSYCHOLOGICAL ASPECTS OF RISK MANAGEMENT

The psychological aspects of risk management are those least understood by systems engineers and architects. Engineering is a discipline of facts and figures with an emphasis on exact answers. The equation must always balance.

While it is true that the equation must always balance, sometimes the terms used to balance it are alien to the engineer. As a profession, engineers tend to precisely measure and predict outcomes of projects. Any approach that does not use this system is often held as suspect and not given much credibility. There are, however, almost dichotomies in any project. The belief that a solution will be found even though one is currently not visible. What is this belief, if not a non–specific approach to a problem? In general there is a belief that there is a solution to the problem and that engineering will find it.

Some reasons for resistance to risk management from a psychological perspective, along with their primary causes are shown below in Table 2.2.

The partial list of reasons featured in Table 2.2 are compiled from a survey of Systems Engineering graduate students. While interesting, thought provoking, and possibly the subject of future research, the data is not being used in this thesis. It is mentioned merely to show that thought was given too many areas of research before settling on cognitive biases as the main theme.

The psychological aspects of risk management are complex and very important to the successful completion of any risk management program. Ignoring this aspect of the process will lead to less achievable results than if the psychological aspects are utilized.

Table 2.2 Reasons for hiding risks

Reason for Resistance	**Psychological Term**
Not wanting to be seen as fallible	**Fear of ridicule**
Fear of ridicule by peers	**Fear of ridicule**
Fear of ridicule by management	**Fear of ridicule**
Ego, I don't make mistakes	**Insecurity**
If I do my job this will go away	**Misplaced Ego**
Corporate culture	**Security**
Embarrassment	**Fear of ridicule**
Not sure how to handle	**Insecurity**
This is not my job	**Transference**

Understanding the subject of Cognitive Biases can help increase the positive results of any risk management program. This is not to say that understanding the psychological impacts on the process will immediately cure all the ills of the process. However, understanding psychological impacts will make successful implementation easier and provide more consistent results.

In general, risk management in today’s engineering environment is approached from an analytical angle. Little, if any, attention is paid to other influences that affect the process. For example, what of the human nature of feelings? What of the political parts of risk management? The work of Helm [Helm, 2004], Langenberg and De Wit [Langenberg and De Wit, 1999], and Ramchandani et al. [Ramchandani, Ligon, Rabensteine and Bhatia, 1994] exemplifies the analytical approach.

Most engineers understand that to ignore the political parts of risk management is counterproductive to the health of the project. It does not take very much time in to see or feel the effects of politics on a project. If a risk's outcome can have negative political consequences, much effort is put into finding an acceptable solution. This political aspect of risk management is well described by Slovic et al. [Slovic, Finucane, Peters and McGregor, 2002] as a part of risk management that demands particular attention.

An example of politics in Risk Management/Mitigation is that the schedule is often more important than full technical compliance. Even budget is often not as important as meeting a deadline. Anything that affects the schedule negatively will receive priority and management attention.

Another aspect of risk management is intuition, the fast and often accurate perception of the problem. While many engineers and program managers actively use the intuitive approach to problem solving, including risk management, it is downplayed and even ridiculed when it is verbalized. The only real approach to risk management is the analytical method.

The heuristic about progress being "90% perspiration and 10% inspiration" is especially appropriate in this area. Risk management is not always just analytical and political. Intuition also plays a major role, though it is most often unreported and downplayed. How many times have you heard “I had a flash of inspiration”? If questioned, the person would downplay the intuitive part and focus on the result.

Another area of importance is how risk is communicated to all stakeholders. Leiss [Leiss, 1996] lists several different ways of communicating risk to stakeholders in a positive manner. These methods include such ideas as “all we have to do is make them partners,” or, “all we have to do is show them that they have accepted similar risks in the past.” These approaches show the necessity of understanding the need for good communication in the risk management process.

2.6 COMMUNICATION IN RISK MANAGEMENT

The idea of formalized risk management is not new. Over the years there have been multiple ways developed to track and manage risks. Perhaps the most common method is the use of the ubiquitous, basic “Risk Cube”. (See Figure 2.1)

The cube is used as a visual aid in the representation of risk likelihood and consequence. The closer the risk is to the lower left corner of the cube the lower the risk is to the project. This encompasses both the likelihood and the consequence of the bad or negative outcome. This basic approach to graphical representation has several areas of weakness, including a lack of granularity and a repeatable way of locating the risk on the chart.

A repeatable method of presenting risk data is generally required for human beings to easily comprehend the situation. Many people cannot relate pure statistics and facts to a real world situation. If a repeatable method of presentation is used, the task of communicating a risk is made easier. It is, however, important that the tool used be appropriate to the task. The tool must provide sufficient granularity for the project without hindering the mitigation plan or micro-managing.

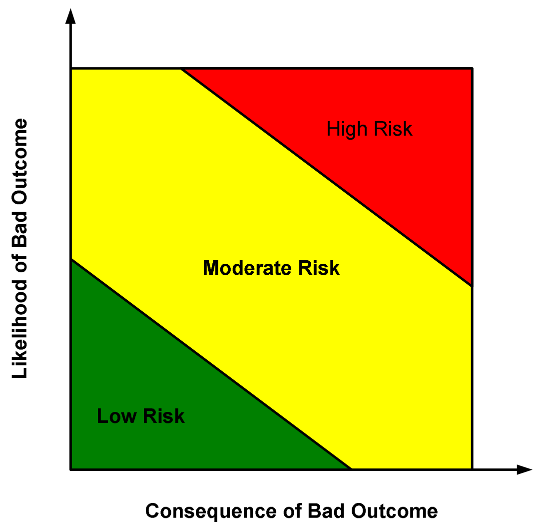

Figure 2.1 Risk cube

The cube shown in Figure 2.2 represents a major step towards a repeatable way to measure risk probability and consequence. The five sided cube provides sufficient granularity without causing stress in deciding which position is correct. This cube, along with a reasonable set of definitions, will provide the Systems Engineer, or any user, with a repeatable way of categorizing and assigning value to risks. Once the system is more user friendly the use of the system becomes a routine task that needs to be attended to on a regular basis.

Qualitative descriptions or definitions of criteria must be established for each of the squares in the cube for both likelihood and consequence. These criteria or definitions add stability and repeatability to the process of risk management/mitigation. Without repeatability, the process loses much of its value and will most likely be seen as a process of minimal gain by all concerned. This process is often called risk mapping.

A structured approach to risk management must be utilized. A lack of structure will undermine the value of the process and limit its effectiveness. This process should include both a set of definitions for the mapping and a logical plan or approach to the entire process.

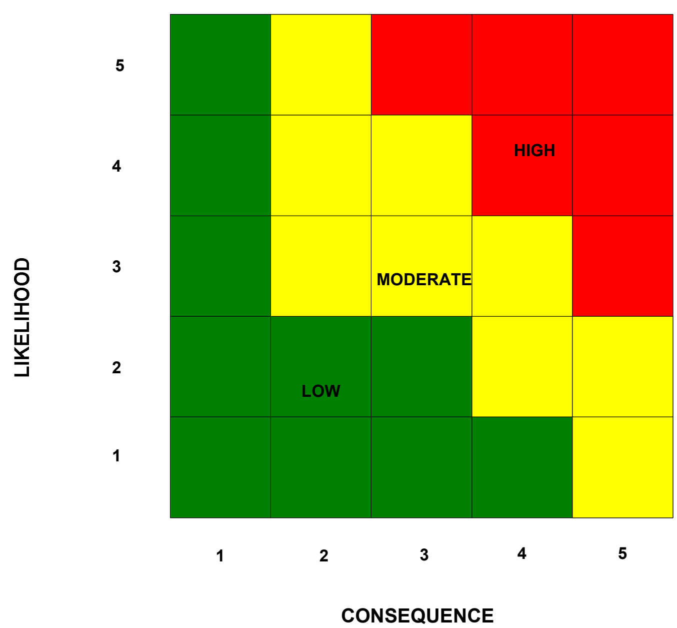

Figure 2.2 5x5 risk cube

Figure 2.3 illustrates a set of definitions that can be utilized as part of a structured risk mapping process. These definitions for mapping provide a reasonably clear path for mapping risk.

Likelihood of Failure —Technology Dependence

Low	Minor	Moderate	Significant	High
No new technology— Systems are off the shelf	Minor modification of existing technology	Dependant on innovative use of existing technologies	Dependant on new technologies that are in development	Dependant on new technologies that not yet funded

Technical Consequence of Failure

Low	Minor	Moderate	Significant	High
Little or no impact program on program objectives	Minor reduction in technical performance with little or no impact on program objectives	Reduction in technical performance with limited impact on program objectives	Significant degradation in technical performance with a major impact on program objectives	Major degradation in technical performance that could jeopardize program success

Figure 2.3 Risk definition

Using a clear path and a structured process such as the one shown in Figure 2.4, a repeatable and predictable risk management program can be implemented. It is essential that a structured path be followed. Without structure, a risk management process will fail. An in depth look at the process is beyond the scope of this thesis, but the following discussion will provide some details of the process requirements.

The risk management process is broken down into several basic steps with the final step being to reevaluate the risk and perhaps identify a new risk.

Risk Identification is always the first step. It is critical to accurately identify the risk. Otherwise, effort may be expended in mitigating the wrong risk.

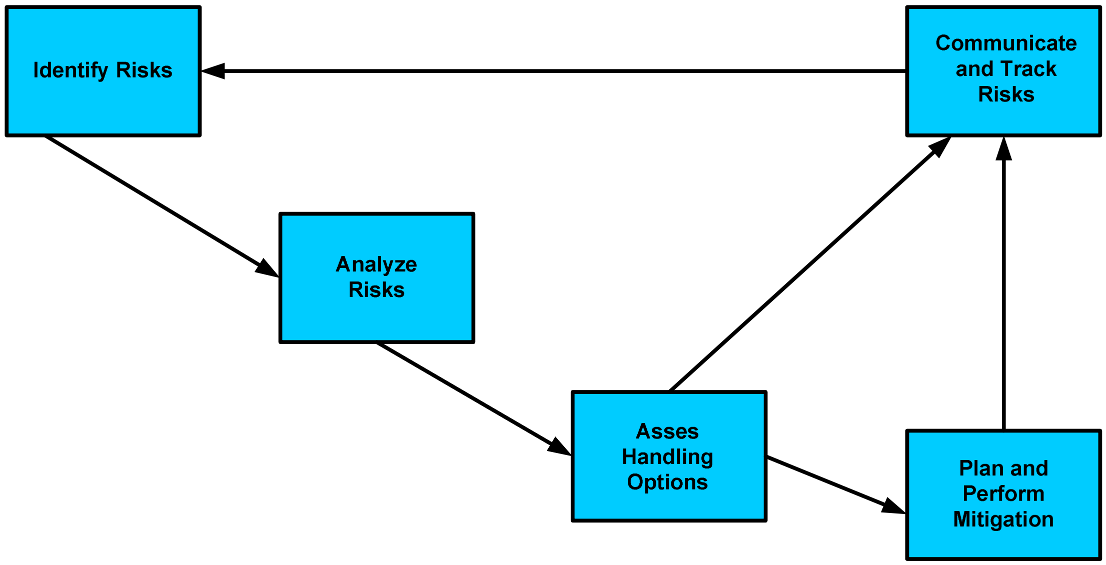

Figure 2.4 Risk management process

How big is the risk? What is the likelihood of its occurrence? Answering these questions requires that the risk identifier and owner, who is not necessarily the same person, along with the rest of the project team, come to a consensus. This step is critical to the process because it sets the tone for the rest of the evaluation.

Next, the consequence to the program in the event that the risk is actually realized must be evaluated. Will there be a major impact on the project? Will the delay significantly affect the budget?

3. COGNITIVE BIAS IN RISK MANAGEMENT

3.1 INTRODUCTION TO BIASES

As with most human endeavors, cognitive bias is possible in the process. Hidden biases often color or distort the perception of the problem. Humans are the sum of their experiences and education, as well as their emotional or non-rational reaction to circumstances.

Research by Smith [Smith, 2006] and Bahill et al. [Bahill, Son, Smith and Piattelli-Palmarini, 2007], among others, leads to the conclusion that people are generally too confident in their ability to solve complex issues, despite evidence to the contrary. An important facet of risk management is the understanding that there is not much difference between risk management and a trade study. As such, risk management needs to have a similar approach taken to reach a solution.

In the area of Risk Management there are many biases. Some of them are overconfidence, training in an area of expertise, aversion to ambiguity in any situation, and life experiences. While this list is not exhaustive, it does illustrate that these biases are common and not unique to any given person or circumstance.

Every project and all of the participants in the project are susceptible to biases. In the area of risk management they are most common in that they tend to show up as strongly held prejudices about how to solve the problem at hand. Overconfidence causes the belief that the risk can be overcome, which is not always true. Or a rationalization that since a solution is not immediately obvious there is no workable solution available, potentially causing changes to the project in the areas of cost or schedule or technical requirements.

3.2 ILLUSTRATIVE EXAMPLE SITUATION

An example of biases in a single project occurred with a piece of equipment that had been in production for several decades. Suddenly this piece of equipment started exhibiting numerous false failures during initial instillation and operation. These failures were not repeatable and seemingly unrelated. Two distinct types of failures were exhibited. Initially, the failures were perceived as irritating and unimportant by all parties concerned. As time progressed and the frequency of both types of failures increased, it became apparent that there was a need for corrective action.

The engineer responsible for the project was very experienced and well qualified. He had many years experience as both a project engineer and a designer, which lead to a cognitive bias of overconfidence. Another cognitive bias in play was the fear of management's displeasure. Management wanted the problem solved with a very minimum impact and little cost. After all, the unit had been working for several decades; how could there be anything wrong with the design?

The causes of the problem in fact both hardware and software design deficiencies. Neither deficiency had previously presented at the same time and the intermittent nature of the failures masked the real issues.

The corrective action required included both hardware and software changes to address the deficiencies. Once the design deficiencies were corrected, the piece of equipment returned to its normal state of proper operation.

The biases of overconfidence and fear of displeasing management played a very important role in the process of risk management. The bias of overconfidence caused the engineer to overlook several clues that, when reexamined, eventually lead to the solutions that were implemented.

3.3 COGNATIVE BIASES IN ACTION

A database of risk assessment was reviewed for potential biases. The review showed that there are probably cognitive biases at play in risk management/mitigation plans. The database spans a five year period and includes 742 records. A compiled listing of the data is shown in the Appendix.

The data in Appendix is in its original state from the data base. The three columns are labeled Risk ID, Likelihood, and Consequence. The data from the database contained much more information which was eliminated due to its lack of relevance to this study. Some records were eliminated from the study due to their lack of an entry in the Likelihood or Consequence column.

The data was sorted in both ascending and descending order as part of the analysis process. At all times the relationship to the Risk ID number was maintained.

The data in the Appendix was sorted for both Likelihood and Consequence in order to present a clearer picture of the forces in play. Several forms of graphical representation were evaluated for clarity of presentation. A bubble chart is used to present a graphic overall view of the distribution of the original data, see Figure 3.1. A cursory analysis shows that much of the data is clustered near of the center of the likelihood and consequence ranges. This clustering will be developed further later in the thesis.

An analysis of the distribution of the consequence of the risk data was done with the results shown in Figure 3.2. This form of the data shows that early in the program that more risks are shown with higher consequence. This data makes sense in that it is probable that while more activity is talking place more risks will be discovered. A trend line, least squares regression, was added to smooth out the effects of the outliers in the data. This clustering of the data adds validity to the idea that risk should be treated as a systems attribute and tracked as such along with cost schedule and technical performance.

Figure 3.3 shows the likelihood data from Appendix A. Probability theory indicates that translations will occur towards the center of the range. The data support this. Probability Theory indicates that translations from 5 to 4 and 4 to 3 will be of grater magnitude than the translations from 1 to 2 and 2 to 3. The data shows more than just plausible evidence of this effect.

The consequence of the risk realization is shown in Figure 3.4. This data also shows that the tendency to place estimates in the center of the range holds true.

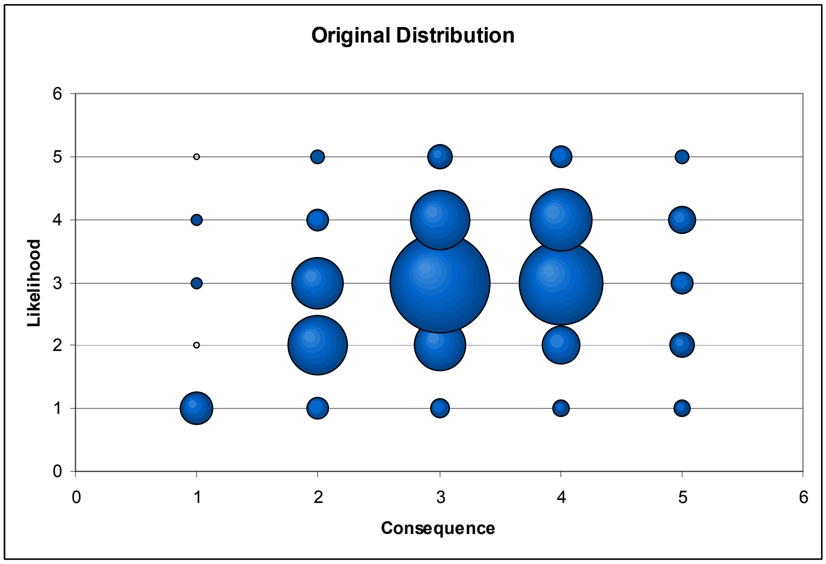

Figure 3.1 Original data distribution of appendix

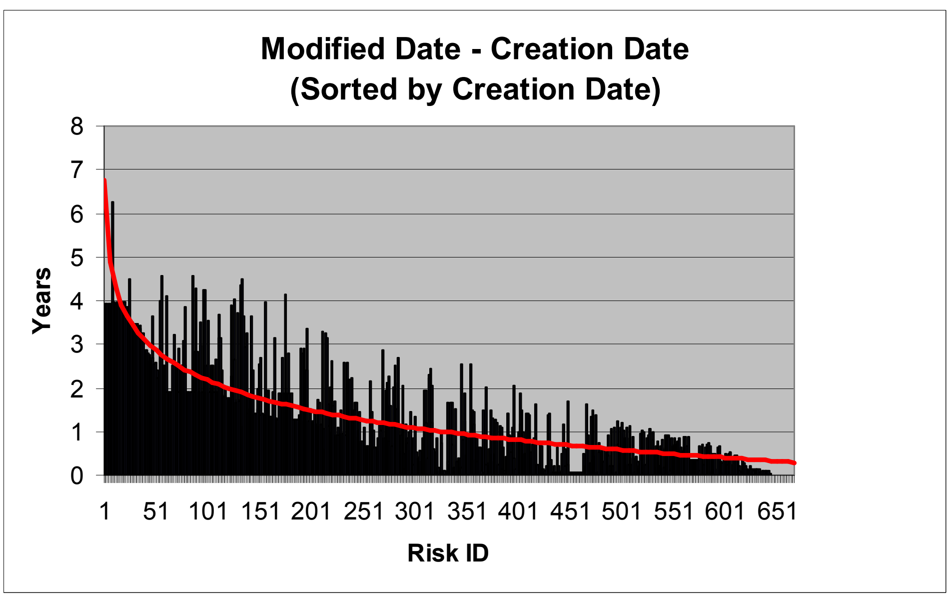

Figure 3.2 Risk data sorted by creation date

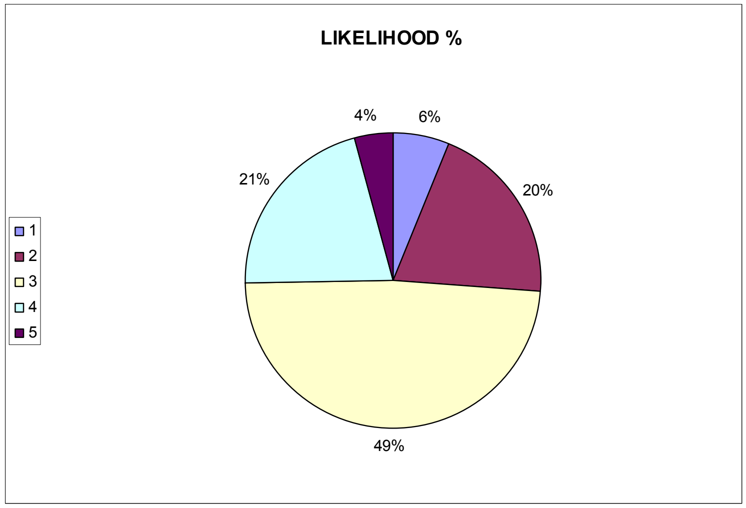

Figure 3.3 Likelihood distribution of risks

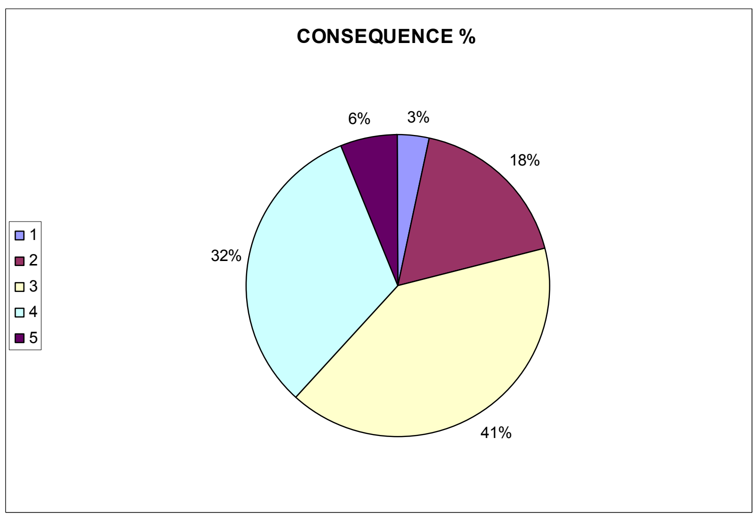

Figure 3.4 Consequence distribution of risks

This tendency to frame towards the center is illustrated by Schwarz [Schwarz, 1990] and the question relating to the number of hours spent viewing television. Two groups of subjects were given a bounded range of hours divided into five time frames, plus an unbounded or open ended range. Both groups of subjects gave the same average answer to the question. The middle field was selected predominately by both groups of subjects, yet the times for each group of subjects were significantly different.

This same force is at play in estimating of the severity of a risk's consequence. In the Optimism Bias, the subject does not believe things are that bad. Fear of Reprisal bias reflects the subject's belief that he or she might loose his or her job. Both of these biases are examples of cognitive biases effecting behavior.

3.4 PROSPECT THEORY

Prospect Theory, as put forth by Kahneman and Tversky [Kahneman and Tversky, 1979], challenged the then prevailing Expected Utility Theory as a descriptive model for decision making under risk. This theory documented flaws in Expected Utility Theory and provided explanations for them.

Prospect theory contends that human decision making entails two stages: an editing stage and an evaluation phase [Kahneman and Tversky, 1979]. In the editing stage, objective probabilities and values are assessed through human utility functions, while the evaluation stage entails the multiplication of expected utility products. For the purposes of this thesis, only the editing stage is important, since the distortion of probabilities and values is examined, but not the resultant risk as a product of multiplication.

One of the effects of Prospect Theory's screening stage is that values are considered not in an absolute sense (from zero), but subjectively from the reference point established by the subject's perspective and wealth before a decision [Smith, 2006]. This is an example of the psychological phenomenon called framing.

Figure 3.5 shows the relationship between estimated and actual probability and consequence [Tversky and Kahneman, 2004]. The hypothesis is that the actual objective probability of a risk being realized and its perceived probability is not the same. There exists a tendency to overestimate small probabilities and underestimate large probabilities. Another way to state this is as the risk gets more personal the impact of the losses become more important.

A graph showing how objective values translate into subjective utilities is shown in Figure 3.6. The utility functions for gains are concave and losses are convex.

It is important to note the significant difference in magnitude with which gains and losses are subjectively valued is approximately a 1-to-2 ratio. [Kahneman and Tversky, 1979]

A modification of the curve in Figure 3.6 yields more interesting data. The inclusion of an expected utility line in Figure 3.7 shows that gains are always worth less and losses are more important.

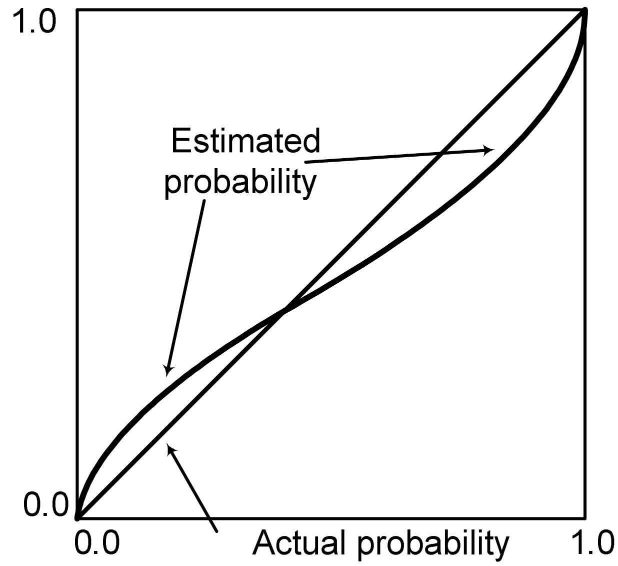

Figure 3.5 Subjective probability assessment compared to actual objective probabilities

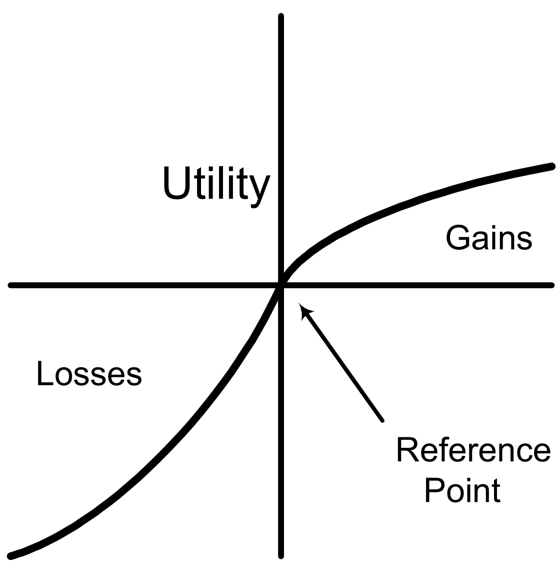

Figure 3.6 Subjective utility versus value according to prospect theory

This is an important example of cognitive bias in the area of risk management/mitigation. Simply put most people are more concerned with losses than in the gains available. The prospect of loosing some wealth is far more important than gaining if there is risk involved.

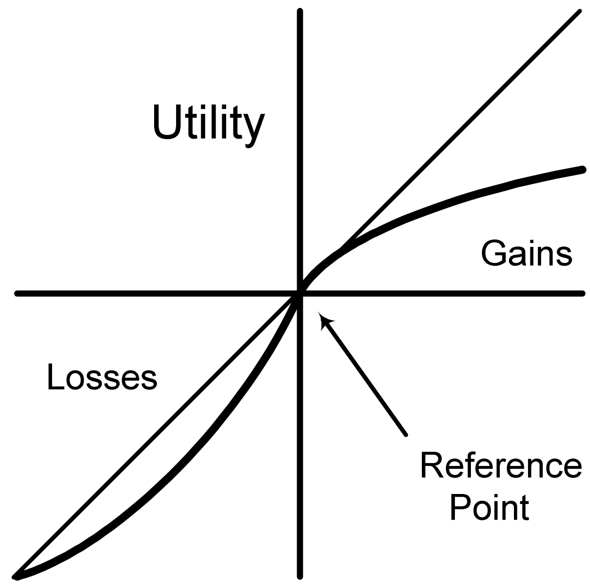

Figure 3.7 Modified subjective utility versus value according to prospect theory

3.5 PROSPECT THEORY AND THE RISK CUBE

Figure 3.8 is obtained by combining Figure 3.5 (subjective probability assessment compared to actual, objective probabilities) and Figure 3.6 (value curve) with Figure 2.2 (risk cube)

Figure 3.5 is used in its complete form for the probability part of the figure. A risk entering the upper part of the curve, a higher risk, has a tendency to be

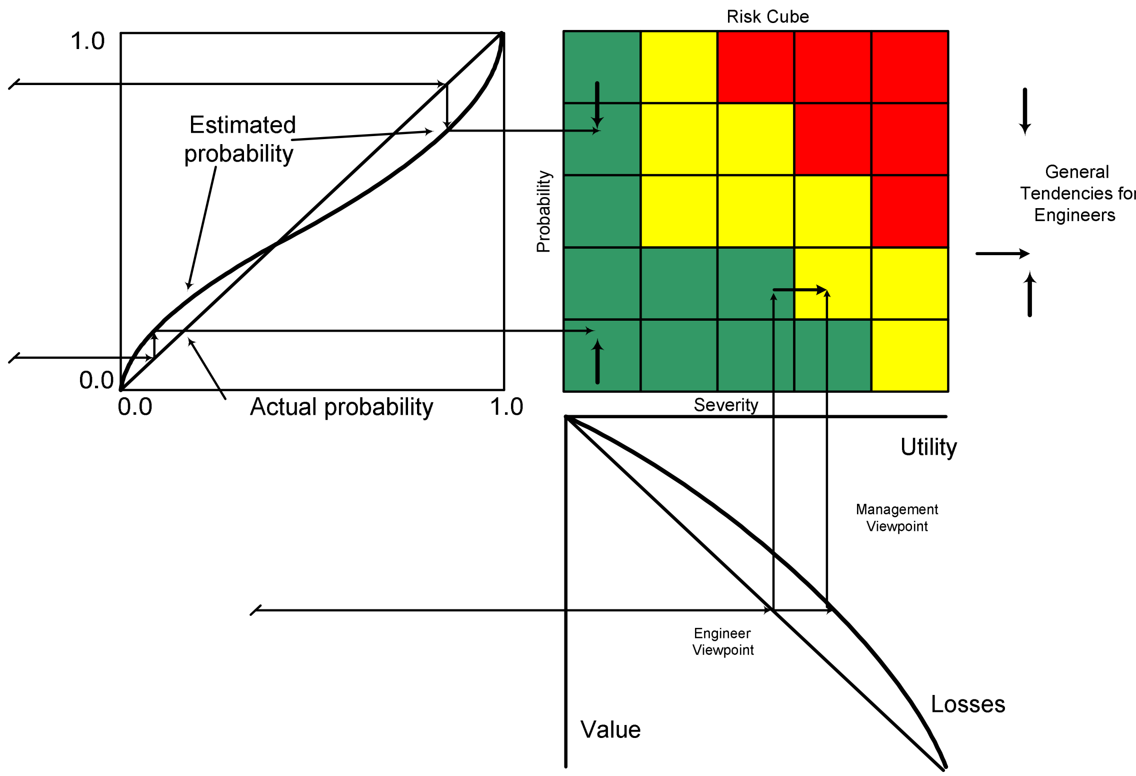

Figure 3.8 Prospect theory and the risk cube

down played and pushed towards the center of the cube. A risk entering the lower part of the curve, lower risk, has the tendency to be pushed towards the center of the cube.

A modified form of Figure 3.6 is used for the severity axis of the curve. The upper right quadrant of Figure 3.6 is used and rotated 90 degrees to the left. This configuration shows the tendency for higher severity risks to be over stated.

An examination of the relationship between the elements of Figure 3.1 reveals some very interesting observations. First, is the tendency to underestimate the likelihood of higher probability risks. Second, the lower probability risks are overestimated.

This is borne out by the data shown in Figure 3.1. The percentage of lower likelihood occurrence risks is significantly smaller than in the middle of the range. This follows the theory put forth by Schwarz [Schwarz, 1990].

An examination of the relationships between the elements in Figure 3.3 also produces some interesting observations. The tendency is to overestimate the consequence of a higher consequence risk. The data shows that there are a larger percentage of higher consequence risks than lower consequence. This fits the theory put forth by Schwarz [Schwarz, 1990].

4. CASE STUDY

One example of Prospect Theory and the Risk Cube in action took place at a major aerospace company from 2004 to 2005. A project was underway to develop a new and upgraded piece of avionics hardware. This hardware was a replacement for an obsolete unit. One of the prime requirements was that the new unit be fully backwards compatible with the existing hardware, meaning that you could use the new unit any place you could use the old one.

To ensure that this requirement was met, the specification for the new unit was intentionally made stricter than that of the obsolete unit. This allowed for some degradation in the performance of the new unit and still ensured better performance than the unit it was replacing. As a normal part of the development process, the requirements were documented and progress was verified on a regular basis.

As the development progressed there was little indication that the unit was in danger of not meeting one of its important specification requirements until late in the development process. Once the likelihood that the unit would not meet the required specification was disclosed by the supplier, a review was initiated. This potential specification shortfall leads to the listing in the risk database. The initial likelihood was determined to be a near certainty. The consequence was also shown to be higher than was actually appropriate. If, in fact, the specification was not met, the condition would not require disclosure to the final customer with the possibility of a waiver required.

The actual parameter that was at risk, while important, had plenty of margin in the requirements. The replacement unit had over a +30% margin in performance over the legacy unit, so there was little chance of not meeting the specification requirement to the customer.

An analysis of the situation showed that, while the lower value of the parameter that was achievable was indeed out of specification, there was adequate margin in the systems design. The lower limit was adopted and the project continued to a successful conclusion.

The initial overestimation of the likelihood and the overestimation of the consequence of this situation illustrate the relationship of the risk management process and prospect theory.

5. RESULTS

The data show clear evidence that the human cognitive biases concerning the judgment of probabilities and values are present in industry. The order of development of this conclusion was as follows:

1) The biases were predicted by theory.

2) The historical data from two programs within one company confirmed the predictions.

Confirmation from data from other industries or companies should be the subject of future papers.

The data also indicates that how and when the risk is presented will influence its level of likelihood and consequence.

6. CONCLUSION AND FUTURE RESEARCH

The data shows that risk cubes are not absolutely objective number grids, but relative and useful means of verifying that risk items have received risk attention. It seems clear that research needs to be undertaken to investigate whether there is a better way of quantifying risks that the ubiquitous risk cube.

Further research also needs to be done in the area of quantifying the relationships predicted by prospect theory and risk classification. For instance, is there a way to help determine if the risk was the subject of a cognitive bias?

Further research needs to be done in the area of psychological impacts in the risk categorization process. The work done by [Slovic, Finucane, Peters and MacGregor, 2002] is a good starting point, but needs to be expanded. The work done by Kunreuther and Slovic [Kunreuther and Slovic, 1996] can also be expanded on in the area of framing its influence on the presentation of risk.

APPENDIX

Risk ID	L	C	Risk ID	L	C	Risk ID	L	C
1	3	4	45	3	4	90	4	3
2	3	3	46	2	3	91	3	3
3	3	3	48	4	2	92	2	2
4	3	2	49	2	3	93	2	2
5	1	2	50	3	4	94	4	4
6	3	2	51	2	3	95	3	1
7	4	1	52	3	3	96	4	4
8	3	1	53	3	3	97	3	3
9	1	1	54	3	2	99	3	3
10	4	1	55	3	3	100	2	3
11	3	2	56	3	2	101	2	1
12	2	3	57	3	3	102	2	3
13	1	1	58	3	2	103	3	4
14	3	4	59	2	3	104	3	4
15	2	2	60	3	3	105	4	4
16	2	2	61	4	3	106	3	3
17	2	2	62	3	4	107	2	2
18	3	2	63	3	5	108	3	3
19	1	1	64	3	3	109	2	3
20	1	5	65	3	4	110	2	2
21	1	1	66	4	3	111	2	3
22	4	3	67	3	4	112	1	3
23	4	3	68	3	4	113	3	3
24	1	1	69	3	4	114	1	3
25	3	3	70	3	4	115	2	3
26	3	3	71	2	4	116	1	4
27	1	1	72	3	4	117	4	1
28	4	2	73	2	3	118	2	3
29	3	3	74	3	3	119	2	3
30	4	2	75	4	4	120	3	3
31	1	1	76	4	3	121	3	3
32	3	4	77	2	4	122	3	2
33	3	3	78	3	3	123	1	3
34	3	4	79	3	3	124	1	3
35	2	4	80	3	4	125	4	3
36	3	2	81	2	4	126	4	3
37	2	2	82	4	4	127	3	4
38	3	3	83	3	4	128	3	2
39	3	4	84	3	3	129	3	3
40	3	4	85	3	2	130	2	4
41	3	4	86	3	4	131	2	5
42	3	5	87	4	3	132	2	4
43	3	3	88	4	2	134	2	3
44	3	4	89	2	3	136	3	3

Risk ID	L	C	Risk ID	L	C	Risk ID	L	C
137	3	4	184	4	4	237	3	4
138	3	4	185	1	1	238	4	4
139	2	3	186	1	1	239	3	4
140	3	4	187	1	3	240	3	4
143	4	3	188	1	2	241	4	3
144	3	2	189	3	4	242	2	3
145	3	2	190	3	4	243	2	4
146	5	1	191	3	2	244	2	3
147	3	3	193	4	4	245	2	3
148	4	3	194	4	4	246	1	2
149	1	5	195	2	2	247	1	1
150	3	4	196	3	4	248	1	1
151	4	3	197	3	4	249	5	4
152	4	3	206	3	3	250	3	4
153	4	3	207	3	4	251	3	3
154	4	3	208	3	3	252	5	5
155	4	3	209	4	2	258	4	4
156	4	4	210	3	3	259	1	5
157	4	3	211	1	2	260	3	4
158	2	3	212	3	2	261	5	5
159	3	3	213	2	4	263	4	4
160	3	4	214	3	2	264	4	3
161	3	4	215	4	4	265	3	3
162	2	4	216	3	4	266	4	5
163	3	3	217	3	3	267	3	4
164	3	4	218	5	3	268	3	3
165	3	4	219	3	4	269	3	3
166	3	3	220	3	4	270	4	5
167	3	4	221	3	5	271	3	4
168	3	4	222	4	4	272	4	3
169	3	3	223	4	4	273	3	3
170	4	4	224	3	4	274	3	3
171	4	3	225	2	4	275	3	3
172	3	4	226	3	3	276	3	3
173	3	3	227	3	4	277	1	5
174	4	3	228	3	3	278	3	3
175	4	4	229	5	3	279	3	4
176	4	3	230	3	3	280	4	3
177	4	3	231	3	3	281	4	4
178	3	4	232	3	4	282	3	3
179	4	4	233	3	4	283	3	3
181	2	4	234	4	4	286	5	4
182	3	4	235	4	4	287	3	4
183	2	4	236	3	4	289	3	3

Risk ID	L	C	Risk ID	L	C	Risk ID	L	C
290	5	3	345	3	3	389	3	2
291	3	4	346	3	4	390	3	4
293	2	5	347	4	4	391	3	4
294	3	3	348	3	4	392	3	3
295	5	3	349	5	4	393	4	3
296	3	3	350	2	3	394	1	2
297	4	4	351	2	2	395	3	2
298	3	2	352	3	2	396	4	3
299	4	4	353	3	4	397	2	3
300	3	3	354	4	4	398	2	3
301	4	4	355	3	4	399	1	4
303	2	3	356	2	4	400	4	3
305	4	4	357	4	4	401	1	1
306	4	4	358	3	4	402	3	4
308	3	3	359	3	4	403	2	5
309	3	4	360	3	3	404	4	4
310	5	5	361	3	3	405	1	3
311	4	5	362	5	3	406	1	1
317	4	5	363	3	4	407	3	2
318	4	4	364	4	3	408	3	4
319	4	4	365	3	3	409	5	2
320	4	4	366	4	4	410	4	3
321	2	5	367	2	3	411	5	3
323	4	4	368	3	3	412	5	5
324	3	3	369	4	3	413	3	4
325	2	3	370	2	2	414	4	5
326	3	3	371	2	2	415	3	5
327	2	3	372	4	3	416	2	5
328	3	3	373	3	4	417	4	3
329	4	4	374	4	2	418	3	4
330	4	4	375	3	3	419	4	3
332	3	3	376	4	4	423	4	3
333	3	3	377	4	3	424	3	2
334	4	4	378	2	4	425	3	3
335	3	4	379	2	2	426	3	3
336	3	4	380	3	4	427	5	4
337	3	4	381	2	5	428	2	3
338	3	4	382	3	4	429	3	3
339	2	2	383	4	3	430	3	2
340	5	2	384	4	4	431	3	4
341	4	2	385	3	2	432	3	3
342	3	3	386	3	4	433	3	4
343	3	3	387	2	2	434	3	3
344	2	4	388	2	2	435	3	5

Risk ID	L	C	Risk ID	L	C	Risk ID	L	C
436	4	2	497	4	4	561	2	3
437	3	2	498	2	3	562	2	3
438	4	3	500	3	3	563	3	4
439	5	3	501	3	2	564	2	3
440	3	4	502	3	3	565	3	3
441	3	3	506	1	2	566	3	3
442	3	4	507	3	3	567	3	3
443	4	4	508	2	2	568	3	4
444	5	4	509	2	2	569	4	4
445	3	4	511	2	2	570	2	4
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447	3	2	523	2	2	572	2	3
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450	5	3	528	2	2	575	4	5
451	3	3	529	2	2	576	4	5
452	3	3	530	2	2	577	4	3
453	3	3	531	2	2	578	3	3
454	3	4	532	2	2	579	3	3
455	3	3	533	2	2	580	3	3
456	4	4	536	2	2	581	3	4
457	3	3	537	2	2	582	2	2
458	1	1	538	4	3	583	3	3
459	1	1	540	1	4	584	2	2
460	3	4	541	1	4	585	2	2
461	3	3	542	2	2	586	3	3
462	3	3	543	4	3	587	2	2
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471	3	3	551	1	5	595	3	3
478	2	2	552	3	3	596	1	1
479	2	2	553	4	3	597	3	4
481	1	2	554	2	4	598	4	3
482	2	2	555	3	4	599	3	4
483	2	2	556	2	4	600	2	5
484	4	4	557	2	2	601	3	5
487	2	2	558	4	2	602	4	3
495	3	3	559	2	2	603	3	4
496	2	2	560	1	3	604	3	2

Risk ID	L	C	Risk ID	L	C	Risk ID	L	C
605	3	3	649	2	5	693	3	3
606	3	3	650	2	4	694	4	4
607	4	5	651	4	4	695	3	2
608	4	4	652	3	3	696	3	4
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616	3	4	660	3	4	704	3	2
617	2	3	661	2	4	705	2	2
618	3	4	662	5	3	706	2	2
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622	3	2	666	4	3	710	3	3
623	3	2	667	3	3	711	3	3
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625	4	5	669	2	3	713	3	3
626	3	3	670	4	4	714	3	3
627	4	4	671	2	3	715	3	3
628	3	3	672	3	3	716	3	3
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632	3	4	676	4	4	720	3	3
633	3	3	677	4	4			
634	2	2	678	4	4			
635	4	5	679	2	5			
636	4	3	680	4	5			
637	3	4	681	3	4			
638	2	2	682	3	4			
639	3	4	683	3	4			
640	3	4	684	5	4			
641	3	5	685	3	3			
642	4	3	686	3	4			
643	4	3	687	2	3			
644	3	3	688	4	3			
645	3	3	689	3	3			
646	2	3	690	2	3			
647	3	4	691	5	4			
648	2	5	692	3	3			

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VITA

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