DESIGNING A SAFETY MANAGEMENT SUPPORT SYSTEM USING OPEN ARCHITECTURE DATABASES

The requirements of information representation in the support of managers' risk-related decision-making

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SUMMARY

This research was conducted at the Space Research and Technology Centre of the European Space Agency at Noordwijk in The Netherlands. ESA is an international organisation that brings together a range of scientists, engineers and managers from 14 European member states.

The motivation for the work was to enable decision-makers, in a culturally and technologically diverse organisation, to share information for the purpose of making decisions that are well informed about the risk-related aspects of the situations they seek to address. The research examined the use of decision support system (DSS) technology to facilitate decision-making of this type. This involved identifying the technology available and its application to risk management.

Decision-making is a complex activity that does not lend itself to exact measurement or precise understanding at a detailed level. In view of this, a prototype DSS was developed through which to understand the practical issues to be accommodated and to evaluate alternative approaches to supporting decision-making of this type. The problem of measuring the effect upon the quality of decisions has been approached through expert evaluation of the software developed.

The practical orientation of this work was informed by a review of the relevant literature in decision-making, risk management, decision support and information technology.

Communication and Information technology unite the major themes of this work. This allows correlation of the interests of the research with European public policy. The principles of communication were also considered in the topic of information visualisation – this emerging technology exploits flexible modes of human computer interaction (HCI) to improve the cognition of complex data. Risk management is itself an area characterised by complexity and risk visualisation is advocated for application in this field of endeavour.

The thesis provides recommendations for future work in the fields of decision-making, DSS technology and risk management.

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This research would not have been possible without the authorisation of my boss in 1995, Roger Weiss. His support for the research helped to ensure that the project was accepted and funded by ESA. "Merci, Roger".

To my family, without whom nothing would have been possible. Working on the research during weekends and holidays was certainly not an exciting period for Marie-Paule, Alison and Martin. Special thanks go to them for their patience.

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CHAPTER 1

INTRODUCTION/OVERVIEW

Two communication theorems.

Theorem 1: 50% of the problems in the world result from people using the same words with different meanings.

Theorem 2: the other 50% comes from people using different words with the same meaning.

Kaplan (1997)

This chapter forms an overview of the thesis. It will elaborate upon the reasons for conducting the research, define the research questions and identify the underlying objectives. This chapter will also define the structure of the research and the type of results obtained. The research was conducted in parallel with my professional activities as a decision-maker in the field of risk management. Working full-time as a risk manager in a large European organisation as well as conducting research with a University could be considered either as a handicap or as an advantage. The handicaps are minor and already forgotten, the advantages are significant and worth considering before addressing the core of this thesis.

The first major advantage was that I was able to investigate in real time the validity and practicality of the theoretical findings and new ideas which are the focus of this thesis and which have long been a personal interest of mine. The second major advantage was the correlation between the research domain and the broadly defined request from the European Space Agency (ESA) to adapt risk management policy to the real-world demands of business. As is true for any multi-national organisation, ESA does business in a dynamic environment and, in ESA's case, this is embedded in a fast evolving technological context. Therefore, at the individual level, men and women making decisions are confronted with similar turbulence and pace of change. Today, everything moves quickly, to the extent that decision makers increasingly expect to assess the results of their own decisions. This expectation has been made possible by new communication and information technology, and is driven by extreme competition in the marketplace.

1.1 Research Question

This research aims to investigate the requirements of information representation in the support of managers' risk-related decision-making. The findings are used to evaluate the utility of the concept of a 'risk visualisation system' (RVS) within multi-national organisations and to build, and evaluate, a computer-aided risk management monitoring system utilising 'risk visualisation' techniques.

1.2 Research Objectives

The objectives of the research are to:

1. Characterise risk decision-making with particular reference to international and multi-disciplinary environments.
2. Explore different theoretical perspectives on decision-making and consider their impact upon the informational requirements of decision-makers.
3. Identify determinants of effective communication in the context of risk decision-making.
4. Develop criteria for risk management decision support system (DSS) design.

1.3 Justifications for Research

Before introducing the theoretical orientation of this work, I would like to share two experiences that have shaped my perceptions of how to help understand and influence decisions in risk management in a large organisation. The first was when I was sitting in front of the Site Director several years ago and seeing my annual report flying from one corner of the office to the other corner... he missed the paper basket but he was very close. He told me "I do not want to read what you did to improve safety on the site, you are paid for your expertise in that. I want to know, without ambiguity, what you expect from me to reduce risk on the site". He defined in one sentence what had been unclear in my mind for years; we need to understand better how people make decisions.

The second event that triggered my need to do this research was the results of my first investigation to answer the simple question "how do people take decisions?" This involved an interesting confrontation between my Cartesian mechanical engineering background and the imprecision and diversity of answers to this question from experts in cognition.

So is it more valuable to understand how decision-makers actually take decisions in the real-world, or to formulate and impose the ideal way in which they should take those decisions? The experience in the Site Director's office suggests the first has priority whilst my initial investigations into decision-making literature revealed that it is mostly the latter that has received attention.

From a more formal viewpoint, this work has been informed by the normative (i.e. should–be) perspectives of risk management but the practical context of this research does not allow such perspectives to dominate. At 'Université Libre de Bruxelles' during my Safety Engineering degree and at TU Delft University during my Master degree, I learnt a variety of models and systems, some of which are discussed later. Useful though these models are, their limitations are considerable; put simply, the elements in the models are theoretically informative but the 'lines' between the elements are sometimes more important than the elements themselves in the real systems to which they correspond.

In respect of decision-making, modelling what should be and modelling what is are two ends of a problem in which the middle-ground is poorly developed. Middle-ground refers to the type of description that falls between classical mechanics at one extreme, and statistics at the other. Kingston (1996) recognises the relevance of this issue to modelling in risk management and quotes Weaver (1948):

> *"The really important characteristic of the problems of this middle region, which science has as yet little explored or conquered, lies in the fact that these problems, as contrasted with the disorganised situations with which statistics can cope, show the essential feature of organisation. In fact, one can refer to this group of problems as those of organised complexity... problems which involve dealing simultaneously with a sizeable number of factors which are interrelated into an organic whole."*

This research does not attempt to delve into the complex detail of decision-making; the aim is to clarify how to support decision-making. To achieve this, this thesis explores models of decision-making that operate at a higher level of abstraction; such models leave the complexity of decision-making in the black-box of the decision-maker's head. For this reason, the orientation of this work is a practical exercise in reconciling normative and descriptive approaches to risk-decision making and examining how to inform the inputs and outputs to the decision-maker's black box through the application of a decision support system.

1.4 Philosophical Orientation

The main philosophical and theoretical direction of this research has been influenced by three main sources:

1. The viewpoint proposed by Rasmussen (1997) of multi-disciplinary research as a key attribute of progress in risk management in dynamic environments
2. The perspective suggested by Reason (1995) on the contribution of latent human failures in the breakdown of complex systems knowing such failures are mainly created by decision-makers
3. The conceptual basis provided by Silver (1991) for the design of systems that support decision-makers.

1.5 Professional and Organisational Orientation

The following paragraphs aim to orientate the reader to the social, cultural and technological nature of the ESA organisation. The cultural diversity, the large spectrum of technologies used and hazards associated, the communication complexities entailed by a melting pot of people coming from 20 countries etc. All of these elements serve to underline the challenging requirements of information representation in the support of managers' risk-related decision-making.

1.5.1 European Space Agency – organisational overview

The idea of creating an independent space power in Europe goes back to the early 1960s. Believing that union meant strength, six European countries (Belgium, France, Germany, Italy, the Netherlands and the United Kingdom) associated with Australia, joined together in 1962 in ELDO, the European Launcher Development Organisation, to develop and build a launcher system. In a similar fashion, also in 1962, these countries were joined by Denmark, Spain, Sweden and Switzerland to form ESRO, the European Space Research Organisation, to undertake satellite programmes. Ten years later these partners decided to merge the activities of the two separate organisations into a single body. In July 1973, the European Space Agency (ESA) was created. In 1975, Ireland applied to join these ten countries and become a member of ESA. On the 30 October 1980 the final signature ratifying the Convention gave legal existence to ESA. Since then the founding members have been joined by Austria, Norway and later by Finland. Co-operation agreements have been signed with Canada.

The task, which was set for ESA, in Article 2 of the Convention, was "*to provide for and to promote, for exclusively peaceful purposes, co-operation among European States in space research and technology and their space* *applications, with a view to their being used for scientific purpose and operational space applications systems*". The total budget to achieve these aims is approximately 2.5 billion EURO, and ESA employs almost 2,000 people from 14 European member states.

Besides its Headquarters in Paris, the European Space Agency has a number of establishments throughout Europe (ESTEC, ESOC, ESRIN and EAC), as well as a launch base at Kourou in French Guyana, liaison offices in Washington and Moscow, and an office in Brussels for relations with the European Commission.

The ESTEC establishment is located at Noordwijk in the Netherlands. As the European Space Research and Technology Centre, ESTEC is the biggest of ESA's establishments and is the nerve centre for their activities. It is responsible for the management of ESA space projects, the development of which is entrusted to the European space industry. The centre, which employs 1,100 ESA staff and 800 permanent contractors, provides technical support to ESA's ongoing automatic satellite and manned space project activities as well as to Europe's space industry through its specialised manpower and laboratory facilities in all major technical space disciplines. ESTEC is also in charge of defining the scientific and application satellite programmes of the future and developing the new technologies needed for their realisation. The centre's comprehensive suite of environmental test facilities count amongst the largest and best performing in the world. Every year, approximately 46,000 people attending meetings, workshops and other activities visit ESTEC.

1.5.2 Risk manager at ESTEC – job description overview

My job as Risk Manager for ESA has several aspects. The main task is to manage the Industrial Safety (versus Flight Safety) and Security domains for the ESTEC establishment. In parallel I am also the co-ordinator at the corporate level, responsible for harmonising these two domains at all of ESA's European establishments. Since the explosion of Ariane 501 in June 1996 (Lions, 1996), ESA's principal management have been very concerned to define a new risk management policy to promote a clearer and more even-handed treatment of different classes of risks. At ESA we classify risks into three groups: Executive (i.e. risks arising from financial, political and social instabilities); Programme (i.e. risks to our operations and products) and Corporate (which includes occupational health & safety and security). I have been nominated by the Director General as the risk management advisor to the Working Group who has been allocated the task of redefining ESA's risk management policy.

As Head of Site Safety & Security at ESTEC, I am responsible for organising a safe working environment for our 2,000 staff and contractors, as well as the 200-or-so daily visitors to the site. Although ESA has diplomatic status, we choose to follow the Netherlands legislation in Security and Safety. However, the Dutch enforcing authorities do not have the right to come freely on site, authorisation must be given by the Site Director or by myself. We do not apply the Dutch safety regulations in a strict way. For example, we do not comply with certain administrative requirements such as submission of annual or other reports to the Dutch administration. This point is mentioned only to explain the relative freedom that I have to be innovative in my approach to organising safety matters. For the rest, the daily task as Safety Officer is the same as that in any large organisation but with the following distinguishing characteristics:

- The diversity of technologies used, including new technologies in their early development
- The full spectrum of hazards generated by the energies and substances that are used by these technologies
- The amount of technical and laboratory areas
- The high qualification level of staff - about 90% of our staff are university graduates
- The cost of space systems — a single scientific spacecraft costs about the same as a new chemical plant

- The origin and background of managers (14 member States and others such as Canada, USA etc.)
- The number of languages used to communicate
- Operational aspects during spacecraft integration phases and technology in development.

1.5.3 Relationship between PhD research & the real-world

I mentioned earlier a confrontation between the Cartesian and other views of the world; Frøyland (1992) provides a useful deepening of the issue, indeed the quotation embraces the basic concepts that have informed this research:

> *"**Dynamic systems** are normally regulated by parameters. When the parameters change, so do the properties of the system. In particular, the stability of a system may be investigated by considering the results of **small disturbances**. If the disturbances die with time the system is stable, and if the disturbances grow the system is unstable. At some points in the space of parameters some of the properties may change discontinuously as a function of one or more parameters. When linear systems lose stability it is usually obvious why. It may be because the **controlling parameters** have changed exponential decay into exponential growth or because some **boundary condition** is 'violated'. However, many non-linear dynamic systems lose stability for no obvious reason, in which case more or less dramatic changes of dynamic patterns take place. This kind of phenomenon -unknown to the linear theory- is known as a **bifurcation**."*

In this thesis, the dynamic systems in question are organisational systems of work, organisations, and industrial society. The origin and causes of the creation of 'small disturbances' within the organisation needs to be monitored and understood. The challenge is how to avoid any further development of these small disturbances into pathogen processes in our society or companies. Following Reason (1995) those small disturbances could be 'latent failures'. A latent failure is a problem in embryo which is generated today, directly linked with a decision made by a decision-maker. This embryonic problem can grow rapidly or very slowly and can provoke minor or severe damage after a certain time, tomorrow or after tomorrow, in a place far away from the location where the initial decision was taken.

Haimes (1991) suggests at least 90% of organisational failures are implicated in the aetiology of accidents. Four sources of failure exist in every small, medium, large or multi-national company: organisational, hardware, software, and human failure. Of these, the organisational source of failures seems to be most important as this is logically prior to the other forms. One must also consider that the primary systemic origin of latent failures is the result of errors made by decision-makers. Thorough analyses of major accidents show that the main responsibility lies at the management level; this is demonstrated in Rasmussen's (1997) analysis of the complex (multiple contributing errors) pattern of the Zeebrugge accident. In Frøyland's terms and also Rasmussen's, major accidents can be seen as evidence that certain boundary conditions have been 'violated' under the pressure of different types of parameter. The visualisation of possible 'violations' of the boundary of acceptable performance can greatly help to anticipate system behaviours, or bifurcations. In view of this conclusion, bifurcation is explored in detail as a major subject of this thesis.

1.6 Cross-disciplinary Approach

A basic concern in the field of safety, certainly in the major hazard industries, is why — in spite of all the efforts to design safer systems — we still witness large-scale accidents. Over the last ten years, Rasmussen (e.g. 1989; 1997) has developed an argument for a cross-disciplinary approach:

> *"What is needed is a fresh multi-disciplinary approach offering a broader, more dynamic framework for assessing needs and designing framework usable, efficient systems. Taking modelling concepts from engineering, psychology, cognitive science, information science, and computer science, cognitive systems engineering (CSE) provides such a framework."*
>
> Rasmussen (1994)

> *"We are presently witnessing a fast pace of technological change that is difficult to match by corresponding changes in organisations and regulatory rule systems. Furthermore, during a period of fast change, safety cannot be based on experience from past accidents but must increasingly be based on predictive risk analyses. Also the trend toward increasingly large industrial systems with a potential for large-scale losses and damage to people and environment stresses the need for improved risk management. In this situation, it has been widely recognised, that a new approach to* ***risk management is necessary, based on a cross-disciplinary*** *approach to analysis of risk management strategies to be developed for different sources of hazard in a modern dynamic society."*
>
> Rasmussen (1996)

This thesis argues for the utility of the approach to risk management advocated by Rasmussen. The model in Figure 1 shows how different disciplines, such as occupational safety research, major accident research, management and organisational theories, and decision research are integrated in the field of risk management. It illustrates how the integration of knowledge from these disciplines can result in the development of a variety of risk management models. One of the key advantages of Rasmussen's model is that is not linear, but is instead focused on the integration of knowledge and skills from different fields.

Rasmussen's notion of a "cross-disciplinary" approach to risk management is highly relevant for this research. In particular, the research draws upon the different disciplines that are encompassed in the inner circle of the model, labelled "Descriptive models in terms of behavioural traces". In Chapter Three an overview will be provided of decision-making theories, culminating in a discussion of Klein's descriptive theory of naturalistic decision-making (Klein et al, 1993). In order to explain this theory adequately, it will be necessary to first introduce the normative classical decision-making theories, which include Expected Utility Theory. The discussion will then advance to consider Salengros (1999) individual decision-making theory, which falls within the circle on Rasmussen's model labelled "Descriptive models in terms of deviations from norms". This theory incorporates the work of Tversky (1974) concerning the use of heuristics in decision-making and the way in which these can bias the decision-making process. It also relies upon Simon's view that decision-makers do not search for the optimum solution to a given problem, but instead search for a solution that is "good enough" (see e.g. Bazerman, 1990).

Figure 1. Cross-disciplinary Model of Risk Management (Rasmussen, 1997)

In Chapter Four, the concept of decision support systems will be examined in detail, with the discussion drawing upon Senge's (1990) vision of learning organisations in a dynamic environment. Senge's work features in the segment of Rasmussen's model labelled "Management and Organizational Theories".

Reason's theory concerning the role of latent failures in accident causation is emphasised throughout this research. In Rasmussen's model it is contained within the segment labelled "Occupational Safety Research". Wilde's (1994) theory of risk homeostasis, although extremely valuable in its own right, has little direct relevance for this research and so is omitted from the discussion.

Finally, this research refers to several publications by Rasmussen (1989, 1994, 1996, 1997), which fall within the segment of Rasmussen's model labelled "Major Accident Research".

The treatment of Decision Support Systems (DSS) as a technology and as a field of inquiry is facilitated by a very similar approach; indeed, the parallelism between Rasmussen and Silver (1991) is encouraging to both areas. These ideas are enlarged upon in Chapters Four and Five. For the moment it is useful to note that Silver (1991) complements Rasmussen's position by identifying the participant disciplines in the field of DSS. He identifies three necessary segments to the establishment of DSS: Underlying Technology (UT), Lifecycle Processes (LC) and Substantive Decision Support (DS). To Silver these segments are themselves the product of elemental concepts or theories (see Table 1).

UT **Underlying Technology**	**LC** **DSS Lifecycle Processes**	**DS** **Substantive Decision Support**
Computer Science Operations Research/ Management Science	Organisational Behaviour Information Systems Systems Theory	Organisational Behaviour Cognitive Psychology Behavioural Decision Theory and Cognitive Science Operations Research/Management Science Functional Areas

Table 1. Reference Disciplines for Decision Support System Segments (DSS)

A concern in adopting the multi-disciplinary approach is the danger of a superficial treatment of some or all issues; the contents of a multi-disciplinary literature are not necessarily additive. On the other hand, the need for fresh theoretical perspectives and the persuasiveness of the Silver/Rasmussen position justified visiting a wider literature than a strict interpretation (i.e. within "classical" risk management) might suggest. The approach adopted here attempts to balance the width of exploration by deepening research in that subset of topics identified as especially informative, for example within cognitive psychology and decision science. The major concern is to co-ordinate and provide an overview of the large set of ideas that have been produced from the wide exploration of literature and make those connections that support a creative resolution of our fundamental research questions (see point 1.2). The final chapter will obviously propose more explicit conclusions concerning the point of a cross-disciplinary approach in risk management science.

1.7 Risk Visualisation

So far I have explained what I do on a day-to-day basis at ESA, to help to convey the background of a multi-national environment and how this has shaped my research choices. The second message in this introduction was to communicate the difficulties that attend decision-making in risk management, in particular the issue of information use to support such management activities. To investigate such a huge field, four basic research questions are defined and relevant fundamental theories brought into correspondence with them. The last but certainly the most exciting part is Risk Visualisation—an area of research connected to this thesis through the development of a Risk Visualisation System (RVS) to support risk decision-making at ESA.

The design of RVS is not simply built on the theoretical foundations laid by literature study: the metaphor is misleading. The development of RVS is characteristic of a user-centred design approach (e.g. Shneiderman, 1998); the process of design is not linear but creative with many cycles of iteration informing the designer's initial model of the user's needs with new insight gained as a result of implementing the most recent design choices. In simpler terms: learning by doing. Within this research, this process has been a beneficial motor adding impetus to the process of discovery. As Zeleny (1996) notes, action and knowledge are intimately related:

> *"So what is knowledge: knowledge is purposeful co-ordination of action —co-ordinated action is a test of possessing knowledge."*

The objective of a DSS is to influence decision-makers by presenting data in the way they expect. Furthermore, this needs to account for the other processes that allow some portion of data to become information, that is taking into consideration the cognitive processes of the people using a DSS. This is more easily said than done, as there is considerable difficulty in anticipating the informational needs of managers making decisions about risk. It can be asserted that "*Nobody knows what a manager needs to know*" (e.g. Beer, 1997) and, except in the most general terms of competence, this seems axiomatic. In view of this, a designer of a DSS cannot make all the choices for the user. What is required is to leave some flexibility, some freedom, for the user (i.e. a manager) to "design" some aspects of the system; in particular, making selections about the attributes of data and the relationships between data elements.

The design of RVS has attempted to account for these concerns. In the case of the requirement for flexibility, an open architecture database has been used to allow considerable freedom to how a user may connect different data elements (the data originating in incident reports, inspections and audits in the company, even coming from different sites located in different countries).

The need for flexibility reflects the complexity of the decision-maker's environment and the inherent uncertainty that accompanies this. Not only does the designer of a DSS not know what a manager needs to know, the manager often cannot estimate what they need to know in advance of the decision. The real-world complexity is reflected in the database of RVS, not in a straightforward mapping between the world and the database but in the potentially innumerable ways in which the data elements can be linked during a process of interrogation. The object of RVS is not to attempt to be a simulation of the dynamic behaviour of the world but to support the process by which a decision maker can enrich their mental models of the world either in structure or detail, and thereby make a more informed decision. These notions about sharing information conform well to the 'redundancy' principle explained by Morgan (1997). This principle notes that systems such as the brain achieve prodigious feats of computation and memory storage not by sheer weight of neurons but by the dynamic association of different neurons.

In practice, RVS or any open architecture database aims to help decision-makers to visualise or modify their appreciation of alternative solutions when confronted with competing choices and selections. To work, it needs to be simple, fast with pertinent information, and not run over the user's expectations or curb creativity. A detailed description of RVS is provided in Chapters Four and Five.

In conclusion, can we reduce the creation of bifurcations generated by decision-makers by influencing their mental processes when they collect data and process it to determine actions in the system or in wider society. As mentioned earlier the major subject of this research is to investigate bifurcations and how to limit the consequences of those system bifurcations (or latent failures) by using a new way to share and visualise elements in decisions.

1.8 Summary of Chapter One

This is the first example of what follows in subsequent chapters: a summary that aims to capture the major points that address the research objectives mentioned earlier (page 12). In this chapter the principal objective has been "Characterise risk decision-making with particular reference to international and multi-disciplinary environments". In line with this, ESA has been characterised as:

- Having great **diversity** of hazards, technology and location; and of culture, language and technical disciplines

- Operating in an environment typified by **a rapid pace of technological change**
- A **risk profile** that is high consequence, low probability
- A very high proportion of staff that are **scientists** and **engineers**. The importance of this is the likely impact of this staff profile on **risk perception**.

In view of this diversity, organisations like ESA are vulnerable to the modes of failure indicated earlier: those of latent failure, bifurcation, and gradual migration towards the boundary of safe performance.

Another consequence of diversity, with particular regard to the linguistic, technical and cultural variety, is the ambiguity of language and the natural need to support communication through other channels. This is one of the primary drivers for adopting a visual medium for decision support.

DSS design involves a number of disciplines, as does risk management. Hence it follows that this thesis needs to bring together different theoretical streams that are navigated in the following chapters. There is a high level of agreement between the theories and practice of risk management and DSS design: both are connected through the topic of decision-making in risk management here expressed in the development of RVS.

1.9 Chapter Headings

The following is a list of the chapter titles for this thesis and the topics covered within them:

Chapter	Title	Content
One	Introduction/Overview	• Introduction and overview to the research.
Two	Communication, Implications for RVS	• Provide contrasting theoretical perspectives on research problem. • Provide explanatory framework for addressing problem. • Provide organisational context in which to consider individual decision-making. • Inform design of software.
Three	Risk Management Decision Making	• Illuminate how decisions are made (normative and descriptive). • Suggest ways in which decision-making can be supported. • Connect risk-management literature with decision-making.
Four	Decision Support Systems and Information Visualisation	• Integrate DSS literature with the issues raised in Chapters 2 & 3. • Present context of present system development (Chapter 1). • Development of prototype Risk Visualisation System (RVS).
Five	Risk Visualisation & Experimentation	• Demonstrate interaction between problems (Chapter 1) and prototype RVS. • State methodology and hypotheses. • Present results
Six	Conclusions and Further Work	• Discusses the research finding with reference to the new concept of RVS and to academic literature. • Conclusions from research.

Table 2: Summary of Contents of Chapters Within Thesis

CHAPTER 2

COMMUNICATION, IMPLICATIONS FOR RVS

2.1 Introduction

This chapter considers communication, a topic that permeates all other aspects of this thesis. The role of communication is examined from a number of perspectives: information technology, European public policy, self-regulation, human perception and change management. All of these viewpoints share concepts of information and its role in making decisions in organisations. In addition to providing a theoretical foundation for the work, this chapter also serves a pragmatic purpose to inform the design criteria of RVS and its implementation. In this connection, the role of RVS, as a means of communication linking together different decision-makers and experts, is emphasised.

The structure of this chapter is as follows. In section 2.2, we consider communication as the link between *risk management*, *decision-making* and *computer technology* — the three major themes of this thesis. Next, in section 2.3, a simple classical model of communication is presented and discussed in relation to the design of RVS. In section 2.3.1, it is argued that the classical model of communication needs to incorporate a theory of perception to augment an otherwise overly restrictive mechanistic viewpoint. The impact of cultural diversity is considered in section 2.3.2. Perception is further considered in section 2.5. The explanation this far will have concentrated on communication inasmuch as it relates to the design of RVS — however, the topic also relates to the implementation phase where RVS is introduced into the organisation of ESA. Section 2.6 considers how classical communication theory can provide insight into the implementation phase of decision support systems such as RVS. Sections 2.7 and 2.8 highlight the human limitations that need to be acknowledged in the design of information systems, especially those intended to support complex behaviour such as decision-making. In this connection, information overload is discussed and connections made between the design of RVS and current thinking in European Public Policy. The chapter ends with a summary.

2.2 Communication – an Integral Issue

As mentioned at the start of this chapter, the topic of communication permeates this thesis. Communication is the means by which people and things are integrated into wholes — organisations and societies. Communication then, is the theoretical means that integrates the three main themes of this thesis, namely **risk management**, **decision-making** and **computer technology**.

2.2.1 Communication & technology

RVS can be regarded as a part of the new generation of computer systems sometimes referred to as "Groupware" that is often considered in the literature under the umbrella title of a "computer supported co-operative work" or CSCW. The main ideas and evolution of CSCW are well explained by Salvendy (1997). The emphasis in CSCW systems is on the people whose purposes it serves, in the case of RVS, risk management within a multinational organisation. In the mid-1980s, as these types of system were being developed and the first hesitant applications implemented, a link was made between CSCW the so-called "Scandinavian model" of computing. This holds that IT is as much a means of improving the quality of the user's working life, as it is to improve the quality and quantity of work. Within this philosophy, IT design should endeavour to deliver systems which (after Björn Andersen, 1986):

- Assume knowledge task semantics on part of user (that is, to take account of the user's model of the task and its context)
- Allow a high level of discretion to user (leave the user free to adopt different strategies and approaches to their use of the system)

- Enable user modification of system
- Are transparent (users see the task rather than the interface)
- Support learning
- Support personal style
- Maintain and improve social contact
- Do not monitor user's work rate.

The Scandinavian model remained in the margins of the IT industry owing to the dominance of the "systems engineering" view, an advantage secured by the nature of the technology up until the late 1980's. This technology was typified by mainframe hardware running specially written software commissioned by the most senior executives and reflecting their organisational viewpoint (and interests). Typically, the technical interpretation of the organisation's wishes by software engineers, involved little if any communication with the end users. The availability of cheap high-power desktop computers, running powerful, flexible software, connected via LAN technology has been largely responsible for the embrace of the Scandinavian viewpoint. Within Europe, IT has become ICT – Information and Communication Technology as the ramifications of these advances make themselves known. The 1996 European Commission Green Paper (EC, 1996) *"Living and Working in the Information Society: People First"* notes:

> *"ICTs also offer new opportunities in the field of health and safety at work. In particular, the application of new technologies can bring considerable added value to risk assessment activities, the collection, screening and dissemination of information, education and training in occupational safety and health, and for end users..."*

The view taken here, which has informed the development of RVS, is of computer technology as a medium of data exchange, access and processing that links people across time and place. RVS then, is a **human-machine** system rather than a purely machine system isolated from the community it is designed to serve. Seen from this perspective, the operation of RVS is very much an exercise in communication.

RVS communication can be considered in at least two ways. First, before the user interacts with RVS, communication must have already happened to inform them about the purpose of RVS and their role in its operation. Second, there is the interaction between the user and computer across the RVS interface. The different types of use reflect different aspects of the communication process. For example, interrogating RVS with specific goals in mind or browsing the system to clarify their ideas emphasise different aspects of perception on the part of the user.

Whatever use RVS is put to, communication is clearly implied across the interface between person and machine. Perhaps, more importantly, RVS serves communication between different people at different times, and in different places with different worldviews and vocabularies. As Shneiderman (1998) makes clear, designers of computer systems must "accommodate this diversity".

2.2.2 Communication and risk-related decision-making

The subject of risk management provides a second entry into the topic of communication; this part focuses on the communication aspects of risk decision-making (decision-making is discussed in detail in Chapter Three). The job of the safety manager/adviser is not one of ownership as the decisions that achieve the goals of risk management are in the hands of others. The job is more a matter of influence upon decision-makers. A gross approach to this is to limit the scope of decision freedom through establishing rules, whether these are termed standards, codes or regulations. However, the success of this approach is limited by a number of factors. Chiefly, the rule-maker cannot legislate for all circumstances nor can they keep pace with changes in the organisation or technology that may leave a rule-based approach out-of-date and risk control compromised. This is particularly true in an organisation typified by rapid technological change - as is true of ESA.

Rule-based approaches may also discourage decision-makers from ownership of risk issues. Booth (1993) advises that rules may engender "unthinking compliance"; decision-makers may feel that compliance with rules is the entirety of the duty and consequently fail to incorporate health, safety and environmental consequences into their everyday decision-making.

As Chapter One indicated, within ESA we are privileged to have a high proportion of scientists and engineers; a considerable knowledge resource that could be brought to bear on the management risk. However, whilst the information and knowledge required to manage risks may be available to the organisation, it is distributed throughout the organisation and not accessible to decision-makers in a form or at a time when they need it. Hence, as well as improving ownership of the issue, we also need to improve support of decision-makers through provision of timely, relevant information. Such information may arise from other decision-makers from earlier work (stored in databases) or from risk experts.

In summary, responsibility without ownership and may result in decision-makers, who have access to information not available to rule-makers, not using this advantage to secure risk management goals because these [goals] are not identified as part of their decision. Additionally, poor access to information and knowledge will also compromise risk related decision-making.

In the United Kingdom (UK), this problem was recognised by Robens (1972) at the level of government:

> *"The most fundamental conclusion to which our investigations have led us is this. There are severe practical limits on the extent to which progressively better standards of safety and health at work can be brought about through negative regulation by external agencies. We need a more effectively self-regulating system. This calls for the*

acceptance and exercise of appropriate responsibilities at all levels within industry and commerce. It calls for better systems of safety organisation, for more management initiatives, and for more involvement of workpeople themselves. The objectives of future policy must therefore include not only increasing the effectiveness of the state's contribution to safety and health at work but also, and more importantly, creating the conditions for more effective self-regulation." (paragraph 41)

The outcome of this thinking is that decision-makers (whether managers or workers) need to recognise their duty but, importantly also need to improve their state of information to discharge it effectively. However, safety information has traditionally been the province of the expert and communication about safety very much the vehicle of the expert. In balance to this, the expert *is* important. For example, the expert is a means of interpreting signals/messages in the organisation, to perceive patterns where others see noise and to provide a conduit of information into the organisation (from professional sources). Indeed this is a definitive aspect of expert operation and one that is incorporated in the design of RVS both to help the expert gain in information and to help decision-makers benefit from the insights and knowledge of the expert.

2.2.3 Communication and power

Taking up the theme more generally, communication is sometimes bound up with issues of authority. For example the control of communication is often associated with authority and power. It is at its most extreme in strongly hierarchical organisations where communication (at least official communication) takes place in a strongly vertical dimension.

Morgan (1997) identifies 14 sources of power in organisations, of these, five are closely related to communication:

- Control of decision-processes
- Control of knowledge and information

- Control of technology
- Interpersonal alliances, networks, and control of "informal organisation"
- Symbolism and the management of meaning.

Since the inception of e-mail and related groupware, authors such as Shneiderman (1998) have noted the "radically transformational" character of the technology upon established power relationships and patterns of control. The general direction of this transformation is toward flatter organisations, more "diamond-shaped" than pyramidal, and more network-based than hierarchical. In practice, this translates to people being able to send messages **laterally** across "lines of command" and to access information that was previously inaccessible in filing cabinets within offices in other buildings, or other countries. The technology, of which RVS is an example, is much more the servant of managers as decision-makers rather than a symbol of the expert's status within the organisation.

2.3 Classical Communication Theory & RVS

The classical approach to communication can be described as mechanistic. It suggests that communication can be analysed by reduction to the components: source, encoding, message, channel, noise, receiver, decoding, receiver response, feedback, and context. In the process of communication in the risk management context, **perception** is a key factor. For this reason, the classical view of communication is presented and the role of perception in communication is considered. Throughout this section we need to keep in mind the practical nature of our interest... what bearing have these issues upon the design and operation of RVS?

In this section, reference will be made to the notion of first degree and second degree reality. This notion will be discussed in detail in section 2.5.

2.3.1 Classical communication theory and perception

The communication process as seen with classical communication theory is presented below as a schematic (after Fortune and Peters, 1995). See Figure 2: classical communication process.

Figure 2. Classical Communication Process (Fortune & Peters, 1995)

2.3.1.1 Source

The source in the context of this research is "leaders"; *leaders* are people that desire to communicate with others, mainly with other leaders and decision-makers to influence their perception at the second degree. The idea in this research is to increase both the quantity of sources, that is the number of *leaders,* and also the **quality** of the sources' perception.

2.3.1.2 Set of symbols and rules for symbol use

As can be seen in the diagram, communication depends upon there being a common set of symbols and a convention for how these symbols are used. In an unusual setting such as cryptography, the discussion would be of codes and keys; in the social and organisational setting the discussion can be phrased in terms of culture. Morgan (1997) provides a useful commentary:

> *"Shared values, shared beliefs, shared meaning, shared understanding, and shared sense making are all different ways of describing culture. In talking about culture we are really talking about a process of reality construction that allows people to see and understand particular events, actions, objects, utterances, or situations in distinctive ways. These patterns of understanding help us cope with the situations being encountered and also provide a basis for making our own behaviour sensible and meaningful". (page 138)*

Using the terms established in section 2.5, the "second degree" reality is the domain in which the "set of symbols" and "rules for symbol use" are established, modified and maintained between the transacting parties. The symbols themselves are the data that feed perception of the first degree. How ideas and facts can be translated into symbols is considered next.

2.3.1.3 Encoding

Despite its mechanistic worldview, the classical model of communication can be seen in terms of people with a desire to communicate ideas to another person or group of persons. The classical model makes it explicit that ideas must be *encoded* into a form that both properly represents the ideas to be communicated and that is compatible with the transmission medium. The encoding step in communication is the process of representing an idea with a symbol or set of symbols. Thoughts can be encoded into one or several modalities that supply human perception with data about the external environment. The sensory modalities are of unequal importance in human perception, with sight relied upon for 70% of data acquired, hearing (20%), smell (5%), touch (4%) and taste (1%) (Jolivat, 1995).

The idea behind the present research is to encode thoughts into simpler language (i.e. words as symbols) but also into non-linguistic symbols. Non-linguistic symbols have a great potential that is investigated in this thesis. Because of their relative independence from language, images, drawings and pictograms can be considered as near universal symbols. Relative in the sense that some pictures may be ambiguous and need words to resolve their meaning. As the earlier quotation from Morgan (1997) suggests, the limits to "universality" arise from the cultural context of symbols; an important matter in the ESA setting as it exemplifies intercultural communication in a multinational company.

The research focuses on encoding information in a RVS (Risk Visualisation System); the way we encode information must be linked with the way people will decode such information latter in the communication process. In other words, the "medium is the message" to some extent, some of the time. For example: alarm design relies on auditory symbols to get prompt attention and a correspondingly fast change in the receiver's behaviour. On the other hand, a sign indicating "slippery floor" is unlikely to cause such dramatic alteration in overt behaviour.

A special aspect of this study is to find a way to encode more messages than the source might believe is necessary. For example, an incident will promote encoding symbols concerning system deviations that are directly linked with the main causes of the incident under investigation. This is a first level encoding. We need RVS to encode a second level of information (e.g. type of the wall), this symbol will not be used directly but could be used during a further risk assessment, say, when you need to know quickly from what type of material a fire compartment is constructed. These second level data are likely to be left unencoded if the process is burdensome: ease and efficiency of encoding is paramount if RVS users are to provide data of this type.

The matter of second level data also presents a more subtle issue — data that signify *instabilities* in risk control, which sit outside the established framework of risk-management within the organisation. For example types of hazard, work activities, personnel issues that are not accommodated within the audit, assessment and monitoring arrangements existing at a given time. Kingston (1996, page 223) calls attention to this:

> *"Beer's [Stafford Beer's] notions of measurement are based not in the notion of what gets measured gets done ... but moreover - what doesn't get measured is also happening. ... The perception of instability does not require an analytical understanding of the system involved. ... In essence, hazards are states of the system outside of the margins of control. ... Particular emphasis should be given both to (a) deriving measures of more populous events than accidents and (b) utilising these and related data at successive levels in the recursive control hierarchy."*

In practice, we want to maximise the capture of data that permit identification of such instabilities – they are a key factor in RVS providing a means of learning and adaptation to risk management. It is encouraging to consider the message in Beer's insight (Beer, 1997): we do not always need deep analytical understanding of the organisational system or sub systems in order to benefit from data about them. The idea is that a message that says "instability" communicates the necessity for the receiver to change his/her mental model of the world, that is, to alter their second-level perception. In practice this should trigger information searching by the receiver both through RVS and other means and only to stop searching when they have revised and improved their model of the world and acted upon it as necessary.

An important idea for RVS is to be able to catch and translate the system instabilities into the complex process of communication. These system instabilities are filtered into data that allow usable information to be provided for people. The communication process using RVS includes a redistribution of various source perceptions of system instabilities to other groups in a way that promotes timely action and informed decision-making.

2.3.1.4 Message

The message represents the encoded thought, an envelope that preserves the integrity of the thought when separated from the source and transmitted to the receiver. The simplicity used to create a message that contains our symbols is one aspect of this research. The message media is keywords and photographs and access to messages will made efficient by surfing (i.e. exploiting hyper-linking in the RVS design). It is envisaged that through interaction, the receiver informs the cognitive processes underlying his/her decision-making. However, the other components of the communication process are needed before moving further at this level of detail.

2.3.1.5 Channel

This refers to the means by which the encoded message is transmitted. The emphasis for the research is to use ICT to connect a maximum of decision-makers located in different locations. The architecture of the channel used is a key concern in this thesis and one that needs to take account of non-theoretical imperatives such as cost. Investment in new hardware or software is a significant factor that will guide our investigation as well as the possibility to retain existing databases as part of the channel. RVS will create a high capacity channel that augments the well-established channels that exist locally. There are two further advantages of this: first, continuing the period of return on the financial investment that established channels represent; second, and more importantly, to keep the technical and cultural specificity of each channel.

2.3.1.6 Noise

The term noise refers to anything that distorts the message from source encoder. Long text notes, notes in languages (including jargon) other than those of the receiver can be considered as a noise. Possible solutions are investigated in this thesis. Noise can be of many forms depending upon the characteristics of the channel we want to use.

Another important source of noise that we need to quieten is human perception or emotions that can interfere with the message. Obviously there are serious limits on this: perception is a creative process - it requires some degree of engagement and mental activity of the part of the receiver. However, in the same way as "active listening" promotes better information transfer in the interview setting, strategies for promoting information transfer across the computer interface need to be identified and promoted.

2.3.1.7 Receiver

The receiver is a person or a group of people with whom the source can communicate. The receivers in our case are classified in three categories:

- **Leaders**. A leader can fix into electronic format a message for him or herself that will be used latter (supplementing their memory) or for easy access in other circumstances somewhere far away from the sending place.

  Also an individual leader or leadership group can communicate (intentionally or not) with other leaders and influence them. The idea behind this research is to change positively the perception of leaders in view to motivate the use of RVS. Improve the perception of their first-degree reality, the small window by which they see the world can be made bigger (i.e. have a greater capacity of data gathering than without the technology). The idea is to open more windows and bigger windows as well as to motivate potential RVS users to acquire new data. In other words, the goal at this stage is to motivate people to co-operate in a constructive risk management process.

- **Followers**. These are potential leaders and people who could become sources in the future. A strength of this research has been to motivate them to join the group of leaders by providing a simple tool for them to access the source (an example of the lateral communication mentioned earlier). The majority of followers will stay followers, but they are still actors in the company and therefore able to influence the leader's view or perception in a double loop of feedback (i.e. the second-degree perception). An example at ESTEC is discussed in chapter 5, here we provided training and empowered security staff to encode data about deviations on the site encountered in the normal course of their duties.

- **Decision makers**. This thesis focuses on decision-makers. Their responsibilities and authority place these persons in the pivotal positions of our risk management process, they change the world by their actions or inaction.

2.3.1.8 Decoding

Decoding is the mirror-image process to encoding. The receivers' reception of symbols through the RVS will be actively involved in this step of the communication process. All steps are important; the effectiveness of the whole communication process is decided by the poorest link in communication chain. The receivers will assign meaning to the symbols received – a vital step that sits outside the classical view of communication. As indicated section 2.5, "second degree" reality is the domain in which the "set of symbols" and "rules for symbol use" are established, modified and maintained between the transacting parties. The meaning of a message is largely determined by the "second degree" reality.

2.3.1.9 Receiver response

For us, the important classes of receivers include leaders, followers and decision-makers. All of them will respond in one way or another after decoding the messages. The range can start with doing nothing to a complex sequence of searching for further data or actions. The motivations of people in organisation can be identified at this level and indeed are a key determinant of the outcome of the communication process.

2.3.1.10 Feedback

This element of the communication process can be the origin of frustration or misunderstanding in the field of risk management. Feedback refers to the receiver response as perceived by the source. The impact of the feedback generated by a receiver (e.g. decision-maker) can be identified later in time and somewhere else in space. Taking a safety advisor as an instance of a source, their frustration is motivated by a desire to see the results from proposals they have made to decision-makers. If nothing occurs in their small "window" (reality of the first-degree) open on the world, their perception of feedback is of a disapproving response with the psychological consequences this can generate.

For RVS, this research is keen to provide a means of encoding feedback from the receiver to the source and, further, to encourage feedback at both the first and second degree of reality. In other words, such feedback should in essence communicate, "not only have I received your message about X, but I have been changed in the following Y & Z ways" to the source. Feedback makes communication a two-way or interactive process. It is the main difference between information and communication, between monologue and conversation.

2.3.1.11 Context

The final component of communication is the context; it is the environment in which communication takes place. The thesis concentrates efforts to see the influence of the context and define parameters to optimise the communication context of our RVS to improve risk management in this multinational company. Context can be quite general, as Jandt (1998) puts it:

> *"Culture is also context. Every culture has its own world view; its own way of thinking of activity, time, and human nature; its own way of perceiving self; and its own system of social organization".*

How one defines culture will have an impact upon the result of trying to account for its effects. From the perspective suggested by Morgan (1997) — of culture as patterns **of** thought and behaviour that serve as patterns **for** creating meaning — one can easily imagine the difficulties of using symbols in messages in a multinational setting. The effect of the multinational setting is exacerbated by the overlay of various technical / scientific groupings and, correspondingly, many different cultures and sub-cultures. For this reason the "close approximation" of symbols and symbol use between source and receiver may sometimes not be close enough to sustain effective communication. All the more reason to reduce the reliance on media that have less reliability as shared symbols (such as words and phrases) and promote the use of media (such as photographs) where this reliability is better.

2.3.2 Cultural diversity & communication

Jandt (1998) has observed that "Language creates differences that do not exist in reality". Hofstede (1991). explains the relevance of the cultural dimension in management by using four indices to measure cultural differences in 50 countries. The four indices are described below.

IDV	Individualism vs Collectivism	A low score indicates that the interests of the group prevail over the interests of the individual within a society. For example, South Korea scores 18 on this index. A high score indicates that the interests of the individual prevail in society over those of the group. For example, the USA scores 91 on this index.

PDI	Power Distance	A low score indicates that there is limited dependence of subordinates on bosses within a society. For example, Austria scores 11 on this index. A high score indicates that there is considerable dependence of subordinates on bosses within a society. For example, Malaysia scores 104 on this index.
UAI	Uncertainty Avoidance	A low score indicates that a society has the ability to tolerate uncertainty and ambiguity. For example, Denmark scores 23 on this index. A high score indicates that a society is unable to tolerate uncertainty and ambiguity. For example, Belgium scores 94 on this index.
MAS	Masculinity vs Feminity	A low score indicates that the society tends towards feminity, which is defined as having social gender roles that overlap, and concern with modesty, tenderness, and quality of life. For example, the Netherlands scores 14 on this index. A high score indicates that the society tends towards masculinity, which is defined as having clearly distinct gender roles, with men supposed to be assertive, tough and focused on material success, and women supposed to be modest, tender, and concerned with quality of life. For example, Japan scores 95 and Austria 79 on this index.

Table 3 shows only the 14 ESA member states and their scores on the four indices.

Table 3. Differences in Cultural Dimension amongst ESA States
(Source: Hofstede, 1991)

2.4 Impact of the Classical Model on RVS

We have described in some detail all the components of the classic - mechanistic communication process. This old version of communication process is used to link our view in communication ways for risk management in the context of this research. Using this approach, consequential issues to be accommodated in the RVS design and operation have been emphasised.

- Context or Environment. The context in which RVS will operate is highly complex: technically diverse, decentralised and multicultural perspective. A good understanding of this context is fundamental to interpreting the effectiveness of the RVS prototype.

- Sources or Initiators. Enlarge the number of sources or the quantity of persons encoding data into the risk management system. In a network approach, several knots or nodes are critical in the sense of passing or retaining information. "Leaders" are vital knots considered as sources that facilitate the diffusion and reformulation of messages. They amplify messages both in significance and reach to a wider set of receivers; similarly they translate and enrich a message by adding information not available to the source. This research aims to help them be more self-motivated and regular sources. Often risk management is considered as a field where only experts can be sources. We will demonstrate that all employees can be considered as source for different type of messages. Therefore the encoding process of messages needs to be revised with this objective.

- Encoding or Symbolisation. Until now we identify the boundary as well as the context of the environment to operate our management system and the potential sources. The way to encoding, formulate, define the contents of our messages is the next step. We will split in two levels the encoding phase. Those link directly with the purpose of the encoding process, first level of encoding. And those attached to the encoding phase that will be used for indirect purposes may be not known by the sources, are the second level of encoding. The technique used to encode messages is very simple in our case. No verbal or intellectual skills are necessary. Photos with keywords will be the main format. *The low cost in user time* *and resources to complete the second level of encoding is a major benefit of this research.*

- Message or Envelope. As explained with reference to encoding, the message is the encoded object containing the symbols from the sources. In other words, we use mainly photographs as a support for the message "packing". This choice needs to be informed further to accommodate the effects of the multi-cultural context.

- Channel or Architecture. The means by which the encoded messages are transmitted will be defined with care for the research. Cost concerning hardware, software and time (training, development, encoding or search), is a sensitive element that is universal for all manager. The open architecture of RVS concept includes a central picture database as the core, and this interconnected with the other existing databases.

- Noise. By the extreme simplification made with the encoding phase and message features, we can greatly reduce a major source of noise from the channel.

- Receiver or Decision-maker. The idea explained in respect of sources applies to the receiver. A first measure to improve the effectiveness of RVS is to enlarge the group of people in the three subgroups of receiver we identified: leader, follower and decision-maker. Their feedback in the system will be monitored by changes in the risk perception of the sources as well as the possible impact of the decision maker actions on the real world. The worldview, as explained later, considers the reality of the first degree of the observant, in our case the source.

- Decoding or Visualisation. There is symmetry between encoding & decoding, as such, the principles underlying the decoding of the message proposed in the RVS will be shared with the encoding stage. The way users explore through RVS is also a particular interest of the study. Decoding can be initiated for specific research such "what type of electrical failures did we have last year?" or the decoding can be of a more general kind, helping the receiver inform his/her decision-making. This aspect is explained later in the decision-making chapter. As indicated at the outset, the human-computer interface is of particular interest: it is argued that visualisation techniques provide effective means to present data – bridging Norman's "gulf of evaluation" (Norman, 1986). What counts as "effective" is the subject of much further discussion in this dissertation, both in respect to the communication and interface design issues and novel techniques for risk management.

- Receiver response or Decision and Feedback. Here we are! All that we have considered so far is only to arrive at this step. What have we changed and are we changing in ESA by creating RVS? Are we able to monitor or assess results and impacts on the real world or on the actors in the business process? What would be valid measures of these?

2.5 Communication – Perception as First and Second Realities

The stakeholders considered within this chapter are leaders, followers and decision-makers (defined on page 41). In terms of communication, it is the perceptions of these people that are our focus and need to be accounted for in the design of RVS.

This section considers the human aspect of perception; the computer-based contribution to this process is considered in Chapter Five when we address the black box of RVS. There, the computing aspects of risk visualisation are described. Returning to the current issue, how do people acquire information about the world?

Jandt (1998) suggests that the process of perception can be divided into three stages: selection, organisation, and interpretation and that: *"The first step in the perception process is selection... You learn from your culture to select out other stimuli from the environment"*.

Jandt's multi-stage process of perception can be integrated with the views of Watzlawick (1988) to show the dynamics of the three stages. This is explained next in terms of the illustration in Figure 3.

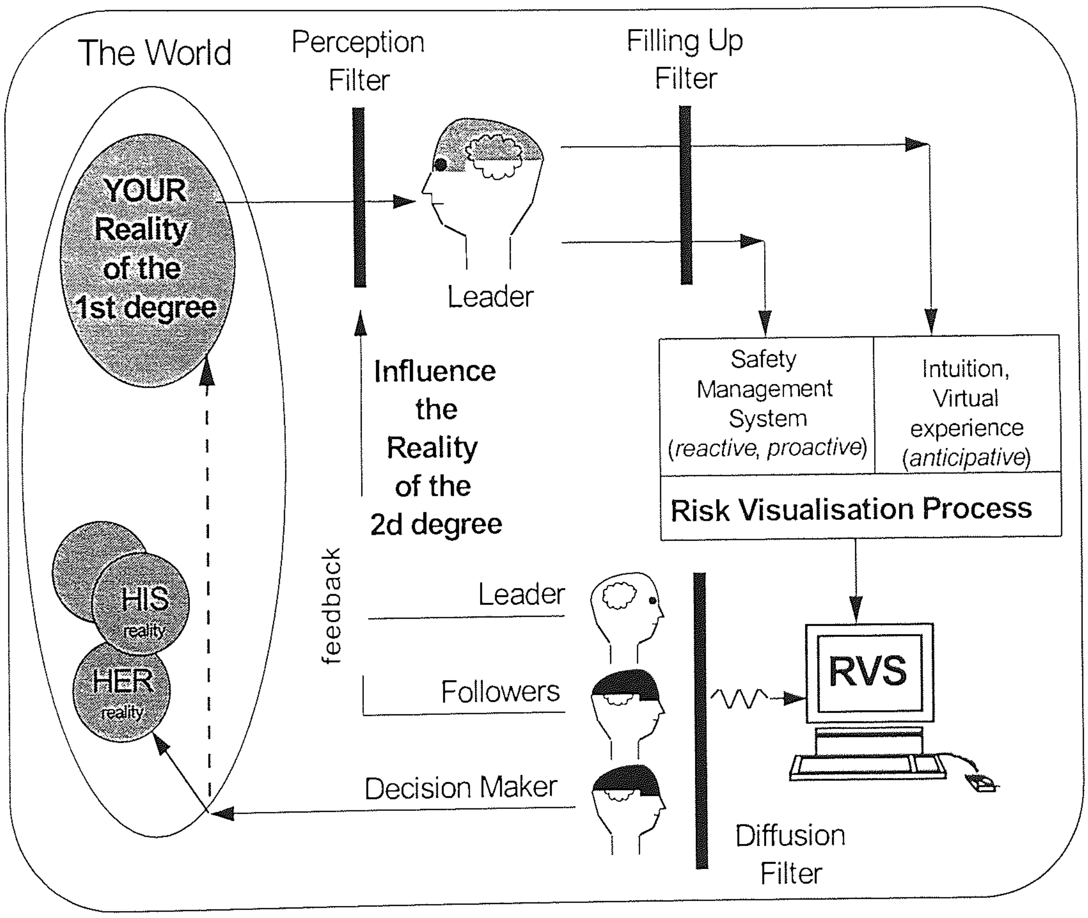
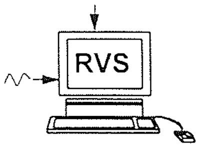
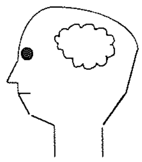


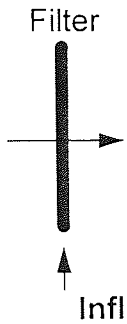
Figure 3. Model of Perception applied to RVS



RVS — the risk visualisation system includes all the databases, visualisation tools and hardware… the “magic box”.

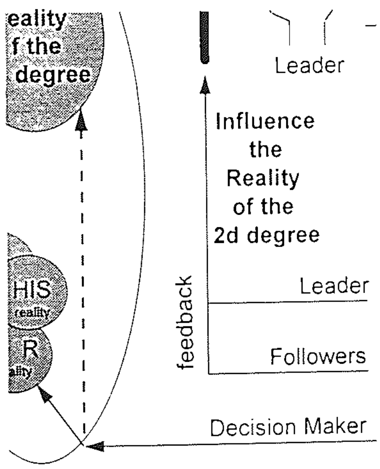


The stakeholders are **people who use RVS**, they are the “magicians” that conjure information and ideas using the RVS.



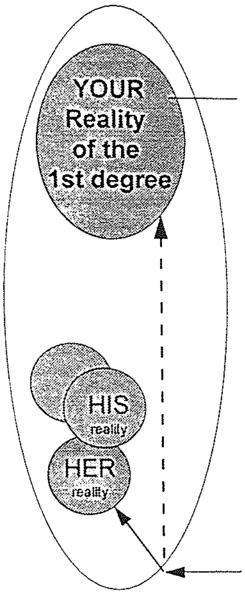
Filters are means of reducing the number of bits of data. There are three main filters:

- Between the World and a leader (the perception filter)
- Between a leader and RVS (the filling-up filter)
- Between RVS and people (the diffusion filter).



The **feedback process** is the influence of people either on other people directly, or indirectly via the world. The diagram shows this feedback originating along two lines. The first is drawn between the leaders and followers to the leader (above) who is looking at the world. The second line of feedback delivers feedback information from the decision-maker, through the world to the leader (above) and also via the leader into RVS where others can be influenced by it.

The World



Realities in our metaphor are the theatre in which the magicians operate the magic box. Communication creates what we call reality. This is not to say that the world does not have an objective reality, however, the subjective reality is just as important in determining decision-making. What we imagine that we know of the world defines our environment – we continually invent or re-invent this environment with the information we receive via the communication process. This environment or mental model of the world can be described using Watzlawick's concept of the "**First Reality**". Another way to explain this idea is to use the window metaphor. We perceive the world via a "window" (small, big, changing or static).

The next aspect on how we invent the "world in our head" involves the influence upon the window through which we view the world. This influence is the property of Watzlawick's **second reality** (also termed reality of the second degree). The first reality window is the sensory data filtered and made available to second reality. The second reality influences the characteristics of the first reality window through which we view the "real world". The criteria that determine this influence exerted by the second-reality are diverse but, as Morgan (1997) points out, reality as defined here is created through the operation of culture (see the quotation provided on page 36). The point here is that the world is perceived subjectively and the processes of perception are strongly influenced by culture. This is considered further in later sections; however, the point made by Senge (1990) is of significance and relevance here:

> *"Vision becomes a living force only when people truly believe they can shape their future. The simple fact is that most managers do not experience that they are contributing to creating their current reality. So they don't see how they can contribute toward changing that reality. Their problems are created by somebody "out there" or by "the system".*

2.6 Implementation of RVS: The Role of Communication Strategy

At the beginning of this chapter, the notion of mass communication was touched on. Although RVS aims to be a tool in the hands of decision-makers rather than an instrument by which senior management restrict their freedom of decision, the **implementation** of RVS has been informed by this literature.

The questions we need to satisfy are of the type "What is in it for you to use RVS"? How are we to motivate the maximum number of people to participate to this novel venture? The answers will provide the basis of a strategy by which to integrate our model into an organisation without undue disruption. Roger (1983) cited by Windahl (1992) identified five qualities of an innovation: relative advantages, compatibility, complexity, ability to be tried and observability.

- **Relative advantages**. To be adopted, something about an innovation must make it worthwhile to consider.

  This is an interesting criterion. What RVS does is actually not achievable by other means currently available to ESA. In terms of the criterion, what are the advantages of using RVS relative to?

- **Compatibility**. An innovation must fit into already existing arrangements, be technical, logistical, or whatever. More important, it must fit into cultural norms and traditions.

  This is a harder requirement for RVS – as it is not merely the ICT aspect but the risk-management approach that is novel. On the positive side, RVS incorporates well-established ESA databases and this should provide some measure of reassurance to new users.

- **Complexity**. The innovation cannot be perceived as too difficult to use or to understand.

For example, the simplicity of inputting data to RVS and of browsing/searching the system. (this is further discussed below).

- **Ability to be tried**. An innovation that can be tried on a limited basis, without total commitment to its adoption, is more likely to be accepted, all other aspects being equal.

  The pilot studies of RVS are a partial satisfaction of this point.

- **Observability**. The consequences of some innovations are readily revealed to others; their uses, benefits, drawbacks, etc. are easy to grasp, making them more likely to be adopted earlier.

  Again, the pilot studies are an advantage here, although wider access is required to fully comply with this requirement.

The strategy that we will develop in the design phase of RVS will take in consideration these five important factors.

2.7 Communication and Bounded Rationality

Earlier a reference was made to the effectiveness of decision-making and the decision-maker's state of information as an important factor in determining this. Morgan (1997), discussing Simon's notion of "bounded rationality", makes it clear that, whilst managers and others in the organisation may accept a duty to make prudent decisions that affect safety, information processing constraints mean that **they can never discharge this duty perfectly**. However, what can be done is to extend their perceptions and data gathering in a time-efficient way through the application of technology such as RVS. Just as mechanical human-machine systems amplify human strength and speed, RVS amplifies human perception – casting the net of data gathering and permitting communication between people that would be impractical by traditional means. From this perspective, the boundaries of RVS cannot be clearly drawn - it is, by virtue of its human "subsystems", an open system. This is in contrast to computer systems of the type criticised by Barker (1998) and Kingston-Howlett (1996). Barker's findings are discussed in Chapters Four and Five, but Kingston's comments capture the point:

> *"Although, the design of computer-based information systems has advanced considerably in terms of speed, usability and connectivity, I believe that there is more to the problem than is likely to be solved by the provision of databases containing the what/why/who/when/how of safety in an organisation and [to] label it a "Management Information System" or "Decision Support Software". The fact is there is too much data and, moreover, even if valid abstractions of the data could be produced in manageable form how, ultimately, could the chief executive produce the appropriate complex of control actions required to enact a particular decision".*

A database of the type Kingston describes is not a whole; it is just a part of a system. From the foregoing discussion, it can be argued that systems that fall within the scope of ICT cannot be properly designed or understood if isolated from their human/social components. The relations of the parts to the wider system are an issue explored in various ways within this thesis.

2.8 Communication and Information Overload

Bounded rationality reminds us that there are limits to human perception, limits that we may not be aware of. However, people are typically aware of their limits to sort and assimilate data and this was implicit in Roger's third requirement (page 52) that innovations should not be perceived as complex.

The issue of information complexity can be considered in two ways. The first, complexity of the interface, is considered in later chapters. The second concerns the perceived complexity of the **data exchanged** with RVS: the information overload – the spectre of the information age.

Salvendy (1997) suggests that we not only face the task of selecting the correct information but, more seriously, face the dilemma of choosing to ignore and reject information. Given the scale of the task – the huge amount of available information – overload is a commonly experienced and worsening phenomenon.

> *"The amount of information that is available is expanding at an ever-increasing rate, to the point where we feel overwhelmed by the almost infinite number of information nuggets we might discover during exploration. This is the crisis of information provision since, if we define information as that which reduces uncertainty, when we have a practically infinite number of information we effectively have no information. However, if we shift the focus of design access to information to selection from information, we start to see the user again as a purposive explorer of information space making sense (literally) by the items chosen but also by those ignored or rejected.''*

It is tempting for designers to create complex systems to show-off their skill or justify their function, or perhaps because they never learned the wisdom of KISS (keep it simple, stupid). As a DSS designer, we must avoid excessive complexity and help the user to avoid overload. Further, as mentioned above, users are more likely to invest effort in learning a new system if keep things are as simple and familiar as possible.

By way of illustration, a colleague – the head of the radiation laboratory at ESTEC – shared an anecdote about simple and complex designs. A European experiment that was destined to fly on the Mir Space Station, had reached the design phase. One of the complex problems was to expose test components to cosmic radiation in the space environment. European engineers designed a very elaborate technical system using a sophisticated engine to open and close a lid outside the station – the estimated cost of this ran into several thousands of EURO. The Russian specialist, more accustomed to delivering low cost designs, designed and built a system with two ropes, a spring and electrical resistor... for few EURO. The electrical resistor will heat-up enough to burn through the rope and allow the lid to open under the force provided by the spring. To close the lid, the astronaut will pull a second rope. This story is appealing because it demonstrates that a simple design does not say "stupid engineer"; simple designs show a mastery of engineering. We must not create complex designs just to show that we are rich.

Returning to the issue of information overload, whilst RVS must be designed to accommodate the abilities and limitations of the users now within ESA, can overload be reduced by improving user performance? The EC Green paper (1996) suggests that the new technology must be accompanied by new skills, in this case informacy:

> *"The ICT revolution plays an important role in the functioning of the labour market, through the reshaping of work, skill structures and the organisation of work. As the new technology is an information technology, it requires not only stronger basic skills in numeracy and literacy, but also a new form of basic skill, the skill of interaction with the new technology, let us call it "informacy".*

Whilst unlikely to be a problem within ESA, whose staff profile is necessarily higher for educational attainment than some organisations, informacy may be a limiting factor (i.e. higher performance would otherwise be technologically achievable) when designing groupware systems. The Green paper goes on:

> *"The real challenge for the transformation and upgrading of skills lies in the re-adaptation of those who are already in the labour force to the new requirements of the Information Society. However, many in the workforce have limited basic skills in numeracy and literacy, skills even more necessary in the Information Society, and a great number have no education and training in informacy. People with outdated or inadequate vocational training find it difficult to re-enter the workforce. Most training and retraining is organised for the young, not for people already in the workplace, or for those who have been working for 10, 20 or 30 years and have lost their jobs".*

Within the Agency, RVS is advocated as a means to acquire information for improved decision-making but without the troubling effects of overload that Salvendy indicates.

2.9 Summary of Chapter Two

In this chapter the main objective has been to "identify determinants of effective communication in the context of risk decision-making". In doing so, the fourth research objective (page 12) has been also partly addressed; to "develop criteria for risk management decision support system (DSS) design".

Communication is a concept that integrates the major issues of this research: risk management, decision-making and information technology. Concerning the last of these, the European Commission has identified this technology as offering advantages to the management of risk and, more generally, has emphasised the communication dimension by coining the term "information and communication technology", ICT.

The communication aspect of ICT is strongly emphasised in the branch of computing known as "computer supported co-operative work", CSCW. The CSCW literature provides pertinent concepts for the design of RVS insofar as:

- RVS allows different people to communicate across time and place
- RVS allows the same data objects to be used by different people for different purposes.

In both cases, contextual information is needed to support meaning; the richness of connections provided by RVS is helpful here.

Returning to European public policy, the message of the EC Green paper "People First..." has updated and underlined the relevance of the so-called Scandinavian model of ICT design. Here, the value of systems is not merely in the improvement of work effectiveness but also the quality of working life. In view of this, DSS design (including RVS) should :

- Accommodate diversity of personal styles of interaction

- Accommodate diversity of technical knowledge and mental models
- Support communication and the sharing of meaning.

The first two are clearly endorsements of Shneiderman's "Golden Rule" for system design: to accommodate diversity of users. The last point stresses the role of RVS in achieving integration of this diversity to the advantage of risk management in the organisation.

Risk management provides the link to the application of communication concepts to self-regulation. Effective self-regulation as described by Robens (1972) is characterised by communication and application of knowledge to recognise and solve risk related problems. Rules alone cannot deliver effective control of risk and decision-makers are often in a better informed position than rule makers. This is especially true in ESA which chapter one has characterised as having a rapid pace of technological change and a high proportion of knowledgeable scientific and engineering decision-makers.

RVS should aim to improve communication between decision-makers and, therefore, improve this aspect of self-regulation. Additionally, RVS ought also to make risk management expertise more available to decision-makers.

The role of the expert is also to be supported via RVS. As indicated in chapter one, the perception of bifurcation is an important means of gaining control of system performance. The early detection of such bifurcation by risk experts using RVS is an important motivation in this research.

The classical view of communication emphasises the mechanistic properties that design of ICT needs to attend to, for example, encoding, decoding and channel properties. However, the classical model does not give adequate weight to the impact of perception and the cultural derivation of meaning. Perception is a key component of communication and is emphasised in this research. Perception is a creative and subjective process that DSS design aims to support. The first aspect here is the communication of data from other times and places to the decision-maker: effectively widening their window on the world. The second issue is that people filter information selectively: their window on the world is coloured by previous experience, culture and technical background. Therefore, there is a role in RVS to influence the filter that people use by supplementing their mental models with knowledge linked by the RVS system to the main objective of their concern.

Communication is relevant not merely to the design of RVS but also to its implementation into the organisation. This issue is addressed using the criteria provided by Windahl (1992) and, in essence, are about the communication of a design intent and method of use to the population concerned.

Lastly, the design of ICT needs to be matched to the abilities of users to assimilate data. A plague of this early stage of the "information age" is information overload", an effect produced by two main factors: inadequacies in the designer's model of the users; and the user's competencies for interacting with such systems. The latter is described by the relatively recent term informacy. The EC Green Paper (ibid.) places great emphasis on informacy as a skill that rivals numeracy and literacy as essential skills in modern working life. In ESA we have the privilege of a high level of informacy but it should be noted that this may not be true of other organisations.

CHAPTER 3
RISK MANAGEMENT DECISION MAKING

3.1 Introduction

According to Salengros (1999) decision-making is an immensely complex psychological activity. Although there has been extensive research into decision-making, nobody knows for certain how people psychologically process decisions before they take actions that influence the world.

The chapter fits into the framework provided by the research objectives in Chapter One in the following way. In section 3.2, it examines the nature of decisions and considers the characteristics of decision-making behaviour. In section 3.3, it examines the comparative strengths and weaknesses of three different approaches to understanding decision-making: classical decision theory, Salengros' individual decision theory, and naturalistic decision-making. Because the discussion is highly theoretical, relevant examples are provided that are drawn from personal experience. In section 3.4, it integrates decision-making with the analysis of communication from Chapter Two, and sets this within the context of risk management within the international, multi-disciplinary environment at ESA or a similar organisation. This provides the foundations for the approach to supporting risk management decision making that is taken with the RVS software, as introduced in section 3.5. The chapter ends with a summary, see section 3.6.

3.2 Decision-making

In risk management there are several reasons why it is important to study the decision-making process. It is only through such study that it is possible to gain a better understanding of the strengths and limitations of the psychological processes that underlie decision-making. This can help us to identify the factors that influence the effectiveness of decision-making, and provide insight into what can be done in risk management to improve the decision-making process so as to increase the likelihood of a decision-maker making a good decision rather than a bad decision. An understanding of decision-making can both improve our awareness of the motivations and adequacy of our own decisions, and improve our ability to understand and anticipate the decisions of others.

To summarise, decision-making theory can provide insights that can help to:

- Present action proposals more clearly to a decision-maker, to highlight their usefulness
- Present these proposals in a manner which is more likely to influence favourably the choice made by a decision-maker
- Improve a decision-makers ability to justify a decision to those who have to implement it
- Enable individuals to contribute more effectively in group decision-making
- Enable decision-makers to take into account more fully the implementation issues when making a decision.

3.2.1 What is Decision-making?

What is meant by the concept of 'decision-making'? This is the question that comes to the mind of most individuals within an organisation when they are required to attend a training course on risk management decision-making. It is often quickly followed by a second, puzzled question, "What decisions? Someone makes decisions here? I didn't know!".

Anthropologists have suggested that the ability to make decisions is the crucial factor that distinguishes humans from other forms of life. Individuals continuously make decisions during the course of everyday life but are rarely aware of the psychological mechanisms that underlie the decision-making process. Most of these decisions are on minor matters, such as the route that we choose to drive to work in the morning, or the food that we select for lunch. However, in the context of work, decisions are frequently made which concern far-reaching policies, such as an organisation's fire safety plans or environmental management strategy. Even with important decisions such as these, the individuals who are involved in generating the decision are often not fully aware of the decision-making process in which they are engaged. Important decisions are frequently made which prove to be flawed with hindsight. This is seen time and again in risk management, where major accidents have often arisen as a result of a range of poor managerial decisions, which were taken over a period of years prior to the accident. For example, Challenger, Bhopal, Kings Cross and Herald of Free Enterprise.

Salengros (1999) has suggested that decision-making can be defined as an act of choice between different options and the implementation of the selected option. In everyday life, each one of us constantly makes decisions and has to work out how exactly to implement those decisions. Decision-making is thus a continuous process not an isolated event. In the context of work, decision-making is different to in everyday life, because individuals seldom make important decisions unilaterally. They have to submit decision proposals to their superior officers, and then communicate the decisions that are made in "high circles" to their colleagues. The final decisions often differ considerably from the original proposals, and from what the colleagues were expecting. Nevertheless, it is invariably the professional individual who is given the responsibility for implementing the decisions. To do this, they have to be able to understand and explain the why and wherefore of the decisions.

Kleindorfer et al (1993) have provided a formal definition of decision-making, which is supportive of the view of Salengros (1999). They state that:

> *"Decision making may be defined as intentional and reflective choice in response to perceived needs".*

Many researchers have attempted to identify several distinct psychological phases to decision-making. The general view is that the same phases have to be progressed through by a decision-maker regardless of the importance and complexity of the decision that is being made.

3.2.2 What is decision-making behaviour ?

Salengros (1999) has suggested that there are certain features that are common to all decision-making behaviour, regardless of whether the decision-making is undertaken by individuals, groups, organisations, or societies, and regardless of whether descriptive or prescriptive decision-making theories are applied. These features can be used to help us to identify when decision-making occurs, rather than speculation, wishful thinking or daydreaming. The features are that for decision-making behaviour to occur there must be a deciding agent, and five conditions must be met.

3.2.2.1 The Deciding Agent (DA)

For decision-making to occur there must be a Deciding Agent (DA). This is the individual, group, organisation or society who willingly engage in decision-making behaviour because they wish to reach a decision on a particular issue. The deciding agent is the originator of the sequence of decision-making behaviour. To understand decision-making in any given context, we need to understand who exactly is the deciding agent. With RVS, the deciding agent could be an individual or a group.

When the deciding agent is an individual, a distinction can be made between when they make a personal decision and when they make a functional decision. A personal decision is one that concerns the individual's personal life, such as their family or home. An example of a personal decision is a man deciding where to go on holiday next summer. A functional decision is one that concerns not only the individual but also the community. An example of a functional decision is a worker deciding how to dispose of hazardous chemicals in their workplace. This decision has implications not just for the individual but also for their work colleagues, their organisation and the local environment.

3.2.2.2 The five characteristics of decision-making behaviour

According to Salengros (1999) decision-making behaviour can be identified when the following five characteristics are all present.

1. The deciding agent must possess a certain power

Decision-making entails the concept of power, because there can be no decision-making if the deciding agent is not in a position to decide. It could be argued that the deciding agent must not only possess a certain power, but must be willing to execute that power. In risk management, a risk manager may often have to make and implement difficult or unpopular decisions. They need to both possess and be willing to use power in order to do this. In Chapter Two, it was observed that Morgan (1997) has identified 14 sources of power within organisations.

2. Beginning of execution

Decision-making is the beginning of a series of phenomena that culminate in the execution of actions, which influence the world. Therefore, one of the crucial points to address is whether decision-making behaviour can be said to have occurred if actions are not ultimately executed. Essentially, is the execution of actions the definitive test that demonstrates that a decision has been made?

This is an exceptionally difficult question to answer. The difficulty exists in part because when the deciding agent is an individual, they are not able to execute actions in an empty world. Their attempts to execute actions can be hindered by another person's actions, by nature or even by chance. If the deciding agent attempts to execute a sequence of actions, it is possible for a range of interruptions to occur between their first and last action, which are outside the agent's control. One answer is that there can only be said to be true decision-making behaviour when the deciding agent at least begins to execute actions in the world. In other words, there must be a "beginning of execution".

If a deciding agent does not possess a certain power to decide or does not begin to execute actions in the world, they can only be viewed as a wishful thinker, not a person engaging in decision-making behaviour. Similarly, the focus on a beginning of execution implies that whatever is decided upon by a deciding agent must be conceived as executable. If it is not executable, it is again only wishful thinking, and the person cannot be viewed as engaging in decision-making behaviour. For example, if a risk manager states that they will completely eliminate accidents from the workplace, this is merely wishful thinking, because it is not a realistic objective.

3. Awareness of a range of possibilities

In decision-making literature the image of a tree is frequently used to illustrate the range of possible decisions that are available to a deciding agent. Decision-making is essentially a task in which a person attempts to 'cut down' the range of alternatives that are available to them, removing the least desirable branches, in order to eventually settle on a course of action. A deciding agent can thus only be viewed as having made a decision when they select one possible course of action and stick to it. In order to reach a good decision, the deciding agent must be aware of the range of possibilities that are available to them, and of the interconnections in this network of choices.

4. Pseudo-decisions: the lower border of decision-making

In everyday life, both at individual and community level, most of the decisions that we have to make are in fact pseudo-decisions. These are decisions that are made either by reflex or instinct. It can be difficult to differentiate between decisions and pseudo-decisions. If a particular decision has to be made regularly it can develop into a habit, and thus lie halfway between being a free act and being an instinct.

For decision-making behaviour to exist, the action to be decided upon must have a certain significance. Actions can vary in significance across a whole scale from low to high significance. The deciding agent has to make a preliminary deliberation to judge whether it is necessary to make a decision, rather than a pseudo-decision. The preliminary deliberation is the initial stage of the decision-making process. The deliberation can be more or less rich, with more or less numerous possibilities (options).

As the significance of the action to be decided upon diminishes, the deciding agent reaches a lower border where the need to make a decision rather than a pseudo-decision disappears. Above the lower border, but beneath the upper border, which is discussed next, it is clear that the deciding agent needs to make a decision rather than a pseudo-decision. When the action to be decided upon is of high significance, right on the upper border, the preliminary deliberation can include a consideration of whether rational techniques, such as probability, need to be applied to reach the decision. The same difference exists between the lower and upper limit as between punters who only trust to luck and those who statistically calculate their chances of winning. In the first case, there is a pseudo-decision, not a decision.

5. Obvious solutions: the upper border of decision-making

When the action to be decided upon is of high significance, and when the deciding agent has deliberating intelligence and superior will, it is possible for the need for decision-making behaviour to disappear. When this occurs, the upper border of decision-making has been passed. In other words, the agent is able to foresee perfectly the whole series of possible actions and knows perfectly the whole sequence of events that would result from the choice of one of those possibilities. This means that the deciding agent is able to see clearly that one of the possibilities represents an obvious solution, so decision-making behaviour does not occur.

Until 1950, very few studies were dedicated to decision-making, and they were all based on a more or less deterministic or metaphysical approach. Since then, studies have focused upon the *uncertainty* that is connected to decision-making behaviour. It has been said that the good boss is the one who decides in spite of the surrounding uncertainty. The level of knowledge and the level of uncertainty seem essential to decision-making. Anecdotally, this is reflected in the attitudes that employees hold about managers, where they believe managers to be in the position of being able to make decisions based upon complete knowledge: "The boss, he knows". The reality is that the manager is the one who has to take responsibility and make decisions, to do so whilst never being aware of all of the possible courses of action that are available and recognising the need to take risks because they are in the midst of uncertainty. Uncertainty is the origin of decision-making.

Table 4 summarises the five characteristics that are necessary for a deciding agent to engage in decision-making behaviour.

1. DA must possess a certain **power**.
2. DA must be aware of the **executability** of his or her decision.
3. DA must be aware of a **range** of possibilities.
4. DA action must have a certain **significance** (low limit of RVS decision process)
5. DA possibilities must contain **uncertainty**, no ones must be obvious (high limit)

Table 4. Five characteristics of decision-making behaviour

3.3 Decision-making Theories

There is a long history of research into decision-making. The field of Decision Sciences is multi-disciplinary, and has integrated knowledge and theories from many academic subjects. This is demonstrated in Table 5, the disciplinary roots of the decision sciences (Kleindorfer et al, 1993).

Table 5. The Disciplinary Roots of the Decision Sciences
(Kleindorfer et al, 1993)

Kleindorfer et al (1993) divide decision-making theories into two categories: descriptive theories and prescriptive theories. Descriptive theories analyse how people actually make decisions. They have examined issues like the influence of organisation and structure on decision-making, procedures for reducing conflict in group decision-making where the decision-makers involved may have different goals and objectives, governmental and bureaucratic decision-making, the effect of human information processing limitations on decision-making, the systematic biases and heuristics that people use in decision-making, and the influence of social norms on decision-making.

In contrast, prescriptive theories analyse how decisions should be made according to well-defined criteria. They range from formal axiomatic theories to more informal theories aimed at supporting decision-making. Prescriptive theories have analysed issues like economic decision-making by individuals and organisations, business and military decision-making, optimisation models, transportation and energy system planning, and decision support systems.

In practice it is not necessarily easy to class a particular decision-making theory as descriptive or prescriptive. Kleindorfer et al (1993) have argued that all sound prescription must begin with good description.

The complexity and significance of decision-making phenomena in individual and community life has led many experts to consider how people behave in a decision-making situation. Countless empirical studies are found in the literature on this subject. These studies have been conducted by experts from different disciplines, with the most important contributions having been made by those from the managerial and behavioural sciences. In particular, experts in cognitive psychology have tried to define better the psychological mechanisms that underlie decision-making, and to identify the mental operations that are performed by individuals when they make decisions. This research has been closely linked with the work of experts in computer science who have sought to understand the psychological processes that are involved in decision-making, in order to develop more effective computer systems and decision support tools.

3.3.1 Classical decision theory

Decision-making research has been heavily influenced by classical decision theory. This theory provides the conventional view of decision-making as an ideal, rational or formal process. It originated in the development of normative models that specified optimal decisions in economics and statistics (Savage, 1954, cited by Beach, 1996). Classical decision theory assumes that the decision maker is rational and that they must think logically about the decision that they need to make.

Salengros (1999) has argued that classical decision theory is founded on the assumption that optimal decision-making is based on a logical and analytical approach that consists of a sequence of steps whose principles are the following:

- Situation-oriented diagnostics
- Identification of objectives
- Definition and assessment of options
- Selection of one of these options.

Various theoretical and mathematical decision-making models have been proposed based upon the approach of classical decision theory.

Classical decision theory has been used to compare the behaviour of individuals in particular decision-making situations. This has resulted in questions being raised regarding issues such as: "To what extent are decision-makers rational?" and "When and why do decision-makers infringe formal rationality?". Research into classical decision theory has generated a rather negative image of the decision-maker, who is described as someone who is hardly rational because they do not respect the prescriptions of the logical approach.

The perception of the decision-maker that arises from classical decision theory has been criticised increasingly because it only takes into account the requirements of logic, whilst neglecting other important aspects of real-world decision-making, such as temporal limitations and the cognitive limitations of human information processing. When these aspects of reality are taken into account, a more positive image of the decision-maker begins to emerge.

Because people do not make decisions in a completely rational, logical way, it is important to understand the factors that can influence individual decision-making, such as personality, motivation and risk-taking. As Sauter (1997) has observed, one error that is often made by the designers of decision support systems is that they assume that decision makers are only interested in identifying the "best possible action". This view neglects the seminal decision-making research of Simon, who observed that decision makers do not make the optimal decisions, but instead seek to 'satisfice' - to select an action that is 'good enough' rather than seeking the best possible action. Satisficing occurs because of limitations in data, human information processing ability, decision-making methods, and the psychological limitations of individual decision makers, such as level of intelligence and tolerance of uncertainty (discussed in the next chapter)

More recently Zeleny (1989) has recognised the complexity of decision-making:

> *"A decision is increasingly recognized and accepted as emergent 'harmonious' pattern, properly balancing all decisional components. Recent advances in neuroscience, cognitive sciences and the associated psychological data show clearly that the conventional wisdom of so-called 'rationality' is incorrect ".*

Zeleny has observed that:

> *"We now hold the means of explaining why people remain so stubbornly and extravagantly irrational, ignoring logic, maximization principles and even self-interest, so often postulated by conventional models. The answer appears to be strikingly simple: humans do not maximize functions, but search for recognizable patterns".*

3.3.2 Salengros' individual decision-making theory

Individuals encounter a wide range of decision-making situations during everyday life, which can be more on less sophisticated, more or less hazardous, and more or less significant. Although the exact nature of the decision-making situation may differ, there are certain features that are common to all individual decisions. First of all, decisions are abstract phenomena based on mental operations which are not directly observable, and which are executed more or less consciously. This makes it difficult to analyse and control decision-making processes, both from a theoretical and from a practical point of view. Secondly, decisions result in individuals making conscious and deliberate actions, which have important effects on individual and community life. Thirdly, decisions enable individuals to assert themselves, to express their freedom and to act upon their own life.

Various different types of tasks are needed for individual decision-making. According to Salengros (1999) the most important of these tasks are:

- Interpreting reality
- Selecting information
- Orientation / guidance (or objectives formulation)
- Assessment
- Updating.

The object of the first two tasks is to interpret reality and select information. They are carried out at different stages of the decision-making process in order to understand a given situation and look for possible means of action. The third task, called "orientation", is the central stage because it guides the decision-making behaviours that are adopted to carry out the four other tasks. The last two tasks concern assessing the range of options that have been identified so that one can ultimately be selected and be transformed into actions that are implemented in the world.

Empirical studies have shown that it is necessary for individuals to use various heuristics to complete these tasks. Heuristics are "rules-of-thumb": methods or behavioural guides that simplify what an individual needs to do to complete a task. They are effectively short cuts that speed up the decision-making process but do not guarantee its success. Consequently, heuristics are efficient, although uncertain. Their usage has limitations that may jeopardise the quality of the decisions that are made, and could lead to more or less serious errors.

The main heuristics that individuals use during the execution of the different decision-making tasks are summarised hereafter. The analysis focuses on understanding the decision-making behaviours without assessing them or comparing them to an ideal model. Finally, the analysis is general and does not take into account specific differences depending on the type of situation, type of decision or type of individual. The aim is to provide a general understanding of the intervening mechanisms, including their respective advantages and limitations.

3.3.2.1 Interpreting reality

One of the most important tasks of decision-making is the interpretation of reality. It occurs at various points in the decision-making process, such as during the analysis of the present or future situation, and during the exploration of alternative options. Interpreting reality means structuring perceived information in order to give it meaning, and understanding the present situation. Interpretation is thus closely related to **perception**. When perceived information can't be interpreted, for instance when an individual is interacting with a person whose language they don't understand, it can be difficult to decide upon an appropriate action to take because they are missing an understandable context. This is why interpretation is important in a decision-making process, because it conveys a meaning to the action and it consequently influences the choice behaviours to adopt.

From early childhood, individuals learn to recognise the situations that they experience by means of developing a language and adequate expressions, and storing the situations in long-term memory in schematic forms, known as cognitive prototypes. Cognitive prototypes form a mental storage from which an individual can extract information to identify and label their further experiences. Identifying and labelling a perceived situation using a cognitive prototype is thus a means to interpret reality. The choice of cognitive prototype plays a driving role because it determines exactly how reality is interpreted. An individual tends to use heuristics to select an appropriate cognitive prototype to apply to help them to interpret a situation. Salengros develops the heuristics model originally proposed by Tversky (1974); three heuristics are argued to be at work: the Representativeness heuristic, the Availability heuristic and the Anchoring heuristic.

1. According to the **representativeness heuristic**, an individual searches their long-term memory for the most similar prototype to a perceived situation and labels the situation accordingly. Consequently, the degree of similitude between what is perceived and what is memorised guides the prototype selection. Nevertheless, the process of association is far from perfect. Sometimes a prototype is selected before the survey of long-term memory is completed, which implies that it is unlikely that the most similar prototype is selected. Other times, long-term memory does not contain a prototype that is identical to the present situation. When the individual doesn't take these discrepancies into account, their interpretation of reality is considered incomplete, partial or distorted. Unfortunately, this occurs frequently.

2. The second heuristic is the **availability heuristic**. This suggests that prototype selection is guided by how easily an individual can find a particular prototype in long-term memory. According to this method, it will be easier for an individual to remember a situation similar to the perceived one, as the individual will tend to use this prototype to

interpret the situation. This is subject to distortion when information is disproportionately abundant or memorable for a certain type of event. Even though the event is rare it may be widely reported and so very available in memory. For this reason, people tend to overestimate the likelihood of becoming a victim of violent crime: per head of population this type of crime is rare, but the level of reporting of violent crime cases via the mass media is very high.

3. The third heuristic is the **anchoring fitting heuristic**. This involves an individual acknowledging information that confirms their initial interpretation of a situation, whilst neglecting information that contradicts it. A prototype is selected soon after encountering a situation and is stored temporarily in memory. This prototype serves as an 'anchor' which guides the interpretation of reality. From then on, the individual tends to select only information that has a high correlation with the "anchor" prototype.

According to several theorists, using these three heuristics is an imperfect means of processing the information needed for decision-making. Yet, these theorists seem to ignore the limits of cognitive abilities of individuals (as noted in Chapter Two). They also neglect the costs and time that an individual would otherwise have to spend looking for additional information in order to develop a more accurate interpretation of reality. The devotion of additional cost and time may entail even more harmful risks than those that would have arisen from an inaccurate interpretation of reality, such as a missed opportunity, or a problem degenerating into a crisis situation in the absence of a quick response. Using heuristics allows individuals to speed up the process of making decisions and acting upon those decisions. Further, it limits the search for information, thus saving energy. Nevertheless, whenever heuristics are relied upon there is the risk that pertinent information will be neglected or ignored, possibly resulting in decision-making errors. These errors tend to arise mainly from an abuse of heuristics, such as when an individual persistently ignores less familiar or contradictory information.

3.3.2.2 Selecting information

The first task "interpreting reality" focused on the way that an individual develops their initial understanding of a decision-making situation by using heuristics to identify relevant prototypes from long-term memory. The second task "selecting information" addresses the way in which an individual searches their external environment for information to draw upon when making the decision. This task is therefore part of the interpretation and perception of reality.

In contemporary society, individuals are required to work in an increasingly dynamic environment, changing jobs or careers several times in their lifetime. Therefore it is rarely possible for them to build up a comprehensive library of prototypes in long-term memory which can encompass all of the situations that they may encounter in a particular job. When an individual changes jobs, they may find that the prototypes that they have stored in long-term memory concerning their previous job are not necessary useful for their new job. Similarly, the trend in business towards employing young staff whilst failing to retain the services of existing older staff, creates a deficiency within organisations as the wealth of experience that has been acquired and stored as prototypes in the long-term memory of the latter is lost. These two points emphasise that organisations are frequently in the position of having fewer and fewer employees who personally experienced past situations. With a multi-national organisation like ESA, it can also be difficult for employees to build up a wealth of relevant prototypes in long-term memory because of the constant movement that is required between the different European sites.

In the information age, the individual decision-maker is often faced with an abundance of data upon which they can draw to formulate a decision. The difficulty, however, lies in locating relevant information amongst this overflow of data. This point was discussed in detail in Chapter Two. Individuals tend to use a three stage process to speed up the task of selecting pertinent information for the decision-making process. These stages are described below.

1. The first stage involves an individual **fragmenting the decision-making situation into a set of smaller, less complex decisions.** This means that rather than attempting to make one large, complex decision, an individual instead makes several smaller decisions to determine what actions to take. Sometimes an individual fails to address some of the smaller decisions, because they are already satisfied that they have reached an overall solution to the situation. However, when this occurs, the solution may be inadequate.

2. The second stage involves an individual **searching for information from familiar sources first.** When this first search is completed satisfactorily, the individual may then search for information from less familiar sources.

3. The last stage concerns the **way that an individual searches firstly for information that confirms their initial interpretation of reality.** If the individual is faced with too much contradictory information, they may revise their initial interpretation. However, sometimes when this occurs they may fail to revise their interpretation of reality, and may retain an incorrect or incomplete representation of reality.

The three stages that guide the selection of information for decision-making do not explain everything. They do not take into consideration that in modern society whenever a large amount of cost and time is invested in searching for additional information in order to make a good decision, it can create other risks, such as a business opportunity being missed because of the slowness of the decision-making process or a failure to resolve a problem quickly enough in a crisis situation. These stages need to be integrated in the design of RVS so as to save the risk manager's energy by limiting the time that they have to devote to the search for information. The concept of RVS should reinforce the use of these three stages in a flexible and fast way. The major error that occurs when individuals rely upon these stages in decision-making is that they often bypass unfamiliar information. RVS is intended to provide data, that may otherwise be not be collected by the decision-maker, due to unfamiliarity.

3.3.2.3 Behaviour guidance

The individual usually tries to give a meaning to or guide their activities. Defining such guidance is a task more central and more global than the other tasks of decision making, as it influences behaviour. Although usually called "formulating objectives", it is more appropriate to name it "behaviour guidance" for three main reasons.

Firstly, the concept ‘objective’ implies that an individual establishes a precise target during decision-making that they then attempt to reach in order to be rational. Practically, such a target is often difficult or even impossible to set. This is the case, for instance, when someone is confronted by a situation, that is too novel or changing too rapidly. Secondly, the fulfilment of specific objectives can jeopardise adaptation, particularly if the context evolves and the objectives are not updated in a timely manner. Lastly, an individual who aims to fulfil precise objectives might be prevented from seizing opportunities as they appear, while being guided in another direction than the one set by the defined objectives. It is for these reasons that managers often prefer to define in general terms the direction in which they guide their decision-making behaviour. Occasionally, or for some particular individuals, there can be a clear and precise vision of what is aimed at.

Behaviour guidance is closely linked to the **affective aspects** of decision-making. It reflects the **decision-maker's preferences and values** and forms the energy input of decision-making and action. However, the affective aspects of decision-making are poorly understood because research has focused primarily upon the cognitive aspects of decision-making. Still, research has identified four different methods to define the way that an individual wishes to guide their decision-making behaviour:

1. The first method concerns situations **where decision-making consists of setting one or more precise objectives.** In such circumstances, the reference point is usually more the past than the future when setting future objectives. For instance, when a manager wants to set sales targets, they often rely on the results already obtained by their company in order to make a decision. Defining precise objectives thus aims to guide behaviour by means of a series of gradual fits in view of past experience. This is known as the "incremental approach" and it allows decision-makers to ease the difficulty, or even the impossibility, of predicting the future.

2. A second approach, similar to the one above but applying to new situations, **implies an action to define after hand the behavioural guidance**. For instance when an individual decides to divide a project into phases to accelerate the decision on the other phases, a sort of "forcer la main". For instance, when a manager doesn't know whether he must bet on a new product, he might decide first to test experimentally this product. In this case, action more than thinking is used to define objectives whereas the analytical or formal approach suggests the opposite.

3. The third method that is used to define the behaviour guidance is **rationalization**. This occurs when an individual attempts to justify or explain actions that they have already performed, by proposing intentions that didn't necessarily exist before the actions. For instance, an individual may tell a colleague that they took the floor at a risk management meeting because they had planned to demonstrate support for a new safety initiative, when in reality, their actions were spontaneous (i.e. less premeditated or considered). Another type of rationalisation occurs when an individual decides to buy a particular car because of its technical

specifications and encounters technical problems after the purchase. The individual may then try to rationalise their choice by focusing on other selection criteria, which were not necessarily driving factors at the time of the purchase (e.g. comfort and safety aspects of the car). Thus, **rationalizations are a posterior justification that individuals use to explain acts or decisions made spontaneously**, or to elaborate intentions that didn't exist in the first place in order to appear rational. Such rationalisations are as important as intentions expressed prior to a decision as they both influence the individual's subsequent behaviour.

4. The fourth method that is used to select the form of behaviour guidance, concerns situations where there are incompatible or conflicting objectives. For instance, if a manager is sent by their organisation's headquarters to take charge of an industrial site in another country for two years and to improve the site's production plans; knowing that their time horizon is short, they may find it difficult to devote part of their financial resources to safety training (see Dudley, 1994). The manager may instead want to prove their efficiency by producing good financial results in the site's annual report.

The four methods mentioned above are not recognised by the classical approach to decision-making. In the classical approach, individuals are considered to always act rationally and logically, establishing decision-making objectives and acting accordingly. This linear concept of decision-making is clearly unrealistic. It results in the real-world decision-making behaviour of individuals being classed as irrational. The balance between what is dreamed and what is possible can be differently appreciated by an individual. This imbalance can be devastating when the dream masks the sad reality, but it could be the motor of a wonderful project when people have a vision of something extraordinary and are motivated to spend all their energy in the achievement of this vision. This imbalance between the dream and what is possible can be linked with the inadequacy between the first and the second reality, see the explanation in Chapter Two.

3.3.2.4 Assessment

The three tasks mentioned earlier (*interpretation of reality, selection of information and orientation*) will be fully understood after the presentation of the formulation and the assessment of decision options. The fourth task is the heart of the decision-making process. An individual seems to formulate options simultaneously to undertaking the first three tasks (interpreting reality, selection of information and orientation). The first three tasks often provide input that can be used to assess decision options, to help to eliminate undesirable options and identify the most desirable option. For instance, when the individual progresses through the phase of searching for options it will help to guide people to show directions to be followed to search for more relevant information. The assessment task can be explained with three main stages.

1. The first method is **a sequential approach that scans the options, one after another**. The assessment criteria will be based on minimal conditions to fulfil. If one option does not meet one of the criteria, this option is excluded until one of the remaining options can feed into all the criteria. This method is often adopted when options are not easily available or when we need a solution that matches absolutely all the criteria. The skill, the knowledge, the imagination and the time available are factors that will influence the decision maker behaviour.

   Beach (1996) opts for the notion of "screening", saying:

   "Screening consists of eliminating unacceptable candidates. Choice consists of selecting the more promising candidate from among the survivors of screening".

2. When the different options are more easily accessible at the same time, the decision-maker will eliminate rapidly those that do not meet the minimal or basic criteria and keep the remainder for further analysis. For

instance the basic elimination criteria could be a prohibitive cost or an unacceptable time delay. After this first pass, the few remaining options are carefully assessed using more quantitative parameters to estimate advantages and disadvantages. This method will be used only for a limited number of options due to the time that it consumes and the efforts that are required from the decision-maker in the quantification phases. This method goes more in the direction of "choice" mentioned by Beach (1996), see the previous quotation.

3. The third assessment method is often used to assess risky situations. In a modern industry or company such situations are frequent and therefore decision-makers frequently adopt this method in order to assess decision options. For instance, how a fire fighter assesses the options when they arrive at the scene of a fire, Klein (1993). The method consists of an individual drawing upon the information that they have stored in long-term memory concerning past scenarios that they have experienced in order to assess the current range of options. In the section "interpreting reality", the nature of a cognitive prototype was explained. A past scenario is a more complex form of a cognitive prototype. Each possible option is taken in consideration and associated to a scenario. The more elegant and positive option could be selected for the final decision. The three heuristics that an individual uses for the selection of prototypes during the interpretation of reality phase of decision-making are simultaneously used for the creation of scenarios.

3.3.2.5 Updating

The previous section explained that the task of assessing the possible decision options is closely linked to the selection of one of them. In theory, when a deciding agent takes a decision by selecting one of the available options, the final stage of the decision-making process should be the implementation of the option. However, the implementation process does not always run smoothly, as other factors can interfere. It is possible for the following three situations to arise once a deciding agent has made a decision.

- A decision is taken and another is implemented.
- A decision is taken but this decision is not implemented.
- A decision is taken and this decision is implemented.

Each of these situations represents an end to the decision-making process. This stage of decision-making is referred to as the "updating task" rather than the "implementation task" because it reflects more precisely the notion of the three possible situations.

1. A decision is taken and another is implemented.

This occurs when an individual selects one option, which they believe to offer the best solution to a situation, but they are forced to implement another option which is more in harmony with the cultures, norms, habits or stereotypes that exist in their organisation. This difference between selection and implementation shows that the analysis or reflection is not the only guide for the implementation of a decision. Besides cultures and norms, political battles for power are another type of external constraint, which influence the implementation of decisions.

2. A decision is taken but this decision is not implemented.

Sometimes an individual takes a decision but it is not implemented. This may occur because unforeseen circumstances arise of an economic, political or strategic nature. For example, when a merger occurs, of which only a limited number of staff are aware. Such unforeseen circumstances are numerous and reflect the real-world behaviour of dynamic organisations. Another possible explanation for an individual not implementing their final decision can be found in their personal motivations. For a number of managers, a brilliant presentation to senior management may be more important than the actual solution to an analysed problem.

3. A decision is taken and this decision is implemented.

Two interesting behaviours can be identified, known as posterior "rationalisation" behaviour types.

The first type occurs when the DA compares his decision with his preliminary objectives or when he compares the selected option with those that have been eliminated. These comparisons are often the origin of regrets and inside conflicts. The DA will start a new assessment in order to reduce the stress created by this inner conflict. The rationalisation approach will be used and the person will reinforce the advantages of the selected option and minimise those of the eliminated options. The decision maker rationalises the choice they have made.

The second type of retrospective "rationalisation" behaviour is more dangerous for organisations. When a decision that has been taken proves to be a bad one, the decision maker is often in a very uncomfortable impasse. If they are more company focused, they may confess to their mistake before a disaster occurs, but if they are more career focused, they may instead opt for the "climbing effect" or "escalation of commitment" (Arnold et al, 1998)). When this occurs the decision maker invests more and more time and resources to correct the mistake and prove that their decision was correct. In certain cases such additional investment will help to save face but in many cases it leads to a more perilous situation, for the decision maker or for the company. A well-known example of the climbing effect is the American involvement in the Vietnam War. RVS could help to identify the context prevailing during the period in which a decision was taken. This may lead to a better understanding of the "climbing effect" and support discussion of this with decision-makers.

Table 6 illustrates what was discussed in the previous sections concerning the different types of tasks that are needed for individual decision-making and the possible associated heuristics or situations.

Tasks	Approach
1. Interpretation of reality	a) representativeness heuristic b) availability heuristic c) anchoring heuristic
2. Select information	a) fragment into segments b) search familiar sources c) search to confirm initial feeling
3. Orientation / Guidance	a) incremental approach b) act once to learn from this test c) rationalisation - posterior justification d) situation incompatible with DA goals
4. Assessment	a) scan options, one by one b) clean / eliminate quickly & scan remaining options with care c) stress conditions, scan past scenarios
5. Updating	a) a decision is taken and an other is implemented, b) a decision is taken but this decision is not implemented c) a decision is taken and this decision is implemented, with two posterior "rationalisation" effects: - reinforce the advantages of the selected option or, - opt for the "climbing effect"

Table 6. Types of tasks and approaches for decision-maker

3.3.3 Naturalistic Decision-Making (NDM)

Whilst traditional decision-making theories have provided some valuable insights into human decision-making, naturalistic decision-making argues that these theories do not truly reflect the way in which people actually make decisions in their natural environment. This led to the emergence of a new approach to decision-making in 1989: Naturalistic Decision-Making. Zsambok and Klein (1997) have defined NDM in the following way:

"The study of NDM asks how experienced people, working as individuals or groups in dynamic, uncertain, and often fast-paced environments, identify and assess their situation, make decisions and take actions whose consequences are meaningful to them and to the larger organization in which they operate".

NDM research has focused upon decision-making in high-risk areas, such as the way in which decisions are made by firefighters, pilots and cockpit crews, corporate executives, computer software designers, military commanders, and physicians. The general finding has been that the processes and strategies that people use in naturalistic decision-making are considerably different to those that are proposed by traditional decision-making research (Zsambok and Klein, 1997).

NDM researchers have objected to the traditional approach of comparing the quality of decisions against abstract, "rational" decision-making standards. Although rational and formal models of decision-making may be relevant in a research laboratory setting, they do not allow for the effects of the various contextual factors that are present when decision-making occurs in the real world, and do not adequately model the adaptive nature of real-world behaviour (Zsambok and Klein, 1997). The key contextual factors that distinguish real world decision-making from the traditional decision-making theories are:

1. Ill-structured problems (not artificial, well-structured problems).
2. Uncertain, dynamic environments (not static, simulated situations).
3. Shifting, ill-defined or competing goals (not clear and stable goals).
4. Action/feedback loops (not one-shot decisions).
5. Time stress (as oppose to ample time for tasks).
6. High stakes (not situations devoid of true consequences for the decision maker).
7. Multiple players (as opposed to individual decision making).

8. Organisational goals and norms (as opposed to decision making in a vacuum).

One finding of NDM research is that decision-makers in naturalistic settings are more concerned with "sizing up the situation and refreshing their situation awareness through feedback, rather than developing multiple options to compare to one another" (Zsambok and Klein, 1997). This is particularly relevant to the concept of using the RVS software as a tool to improve decision-making in risk management. As was discussed in Chapter Two, feedback is an essential element of the RVS approach to risk management. The software is designed to allow the risk manager to 'surf' the data that is stored within it, so that they can take on the perspectives of others within the organisation, and use this data to inform decision-making. When the risk manager makes a decision, it is implemented as actions in the world. As the effects of these actions are perceived by employees throughout the organisation, they are recorded in the RVS providing feedback to the risk manager. The RVS approach is thus based around an iterative process of:

- Gathering information from different perspectives
- Analysing this information, reaching decisions
- Implementing these decisions as actions in the world
- Collecting and recording feedback from the different perspectives of those who see the effects of the actions on the world
- Analysing this new information
- Reaching new decisions.

The RVS approach views decision-making as a continuous process of "analysis-decision-action-feedback".

3.4 Decision-making in Risk Management

Decision-making has, so far, being considered in general terms. However, the subject matter – risk management – requires further issues to be explored for relevance to the design of RVS.

Kingston (1996), citing work conducted by the US Nuclear Regulatory Commission (USNRC) makes the point that health and safety matters may be more difficult to manage than other aspects of organisational performance. He suggests that this is due to the low probabilities of health and safety "events" (such accidents and incidents) and the subjective class of adversity to which they belong (typically, the harm of people). Subjective effects on decision-making mediate both of these causes.

It is already been argued that rule based approaches to risk management weaken the ownership by managers of health and safety problems. This happens in two ways: first, by reducing a decision-maker's recognition of situations that require him to make a decision and to act; and, secondly, to fail to properly incorporate assessment of the effects of everyday decisions upon risks to health and safety (and environment) before acting.

In Chapter One, the low probability, high consequence risk profile of the agency was recognised as a distinguishing characteristic. Hence, the USNRC research may well be applicable to the risk management situation at ESA.

Another feature of risk management that has special properties within the subject of decision-making is the perception and interpretation of bifurcation; the often subtle movement of system performance away from control because of (undetected) changes affecting the organisation. The key to addressing this problem is detection and this requires both a position of overview and the means to recognise patterns in data.

These points all indicate that the role of the risk expert, be they a health and safety manager, occupational health specialist or environmental scientist, is in need of clarification. This clarification of roles should be aimed at the organisational hierarchy, the community of decision-makers and, indeed, the risk experts themselves.

The contemporary view of risk management is characterised in health and safety by the Robens' Report (1972) and the EU legislative programme of the 1990's. This reveals that it is the line management organisation, including the workpeople themselves, that has responsibility for safety. The role of the health and safety manager is to be a source of expertise to them and to provide a monitoring and regulatory function to the organisation overall.

Clearly, if the line management believe that the health and safety manager is solely responsible for health and safety they are unlikely to own the work-related safety problems that they are best placed to identify and make decisions about. This is echoing the discussion of information and communication in the previous chapter.

RVS is intended to help to bridge the gulf between the risk expert and other decision makers in the organisation, by reinforcing the role of the expert in the organisation and encouraging others to perceive them as a source of expertise and authority.

One problem that exists which hinders risk management decision-making is the lack of integration between risk management and management in general. Petersen (1996) has made the following observations on this subject:

> *"A number of safety professionals believe that the total effectiveness of safety programming today is seriously reduced by an inability to integrate safety into the regular management systems and by an inability to effectively relate safety performance to corporate goals".*

> *"Too often they are in this ineffective position because they have not demonstrated to management that safety is a management-controllable cost controllable by planning, organization, and management direction".*

Another problem that hinders decision-making in organisations is the inability of managers to see what is going on around them. Mintzberg (1996) made the following remark on this theme:

> *"Too many managers can't even see what is going on at the ground level of their organizations, where the products are made and the customers served (presumably)".*

Clearly, this problem is witnessed frequently in risk management, where time and again organisations fail to see the warning signs before an incident occurs. Often with the benefit of hindsight, we can see an obvious trail of failures or bifurcations leading up to an incident, and can be astounded that the individuals within the organisation did not see what was going on around them at the time. It is easy to forget that in large organisations in particular, it can be difficult to keep track of all that is occurring, especially when there are multiple sites, and it can be equally difficult to identify failures and their possible consequences in real-time. What is needed is a tool that managers and risk experts can use to enable them to see better what is going on around them, and to recognise bifurcations at an early stage and identify their possible consequences and the feasibility of different solutions.

Another problem is that when managers do encounter difficult decisions they often look externally for easy, ready-made solutions. They fail to recognise that they are the local expert and have a wealth of insight and experience on which to draw to develop creative solutions. Morgan (1993) has remarked:

> *"Too many managers are looking outside themselves for answers to their problems".*
>
> *"They are looking for the latest theory and at what successful organizations are doing. They are trying to spot the latest trends. In reality, they would be better off engaging in some critical thinking for themselves, recognizing that they and their colleagues already have a*

vast treasure of insight and experience, which they could and should be using".

"The challenge is to tap this insight and understanding in a constructive way".

This problem is seen in risk management when organisations look to buy ready-made solutions to proactive tasks such as risk assessment, policy writing, incident recording and auditing. These ready-made solutions vary in quality, but in general are rigid and restrictive, and are no match for self-created solutions, which are designed specifically to meet the needs of the organisation and are fully understood by the staff who created them. What is needed is a tool that enables risk managers to tap into their own insight, experience and understanding of health and safety in their organisation, and to recognise problems and develop solutions, which are flexible and creative.

The next of these problems logically follows on from the preceding point. If it is desirable for managers to be able to develop more solutions to problems by themselves, it is equally desirable for them to use creative, sophisticated methods of problem-solving which they can utilise to aid this process. Proctor (1991) has commented upon this:

"Creative problem solving is an important dimension to managerial activity. Rapidly changing business environments produce problems, which managers have not previously encountered. Tried and trusted methods of approaching new problems can meet with failure. The need for creative problem-solving methods, which overcome such difficulties, is of paramount importance. There are a number of established creative problem-solving aids, such as brainstorming, lateral thinking, etc. and a new set of aids which are computer-assisted".

Proctor (1991) also cites Ackoff and Vegara (1988)'s remarks on this subject:

"... manager needs to discover new and better ways to solve problems ... and a structured approach to creative thinking".

The need for new and better problem-solving techniques is evidenced in risk management as much as in the wider context of management as a whole.

The last problem that we will identify here is the failure to address harmful uncertainty. Quite simply, it is easier to focus attention on the problems that we do know about and know how to resolve, than to find ways of actively seeking new problems and investigating areas where much is dynamic and uncertain. As Smallman (1996) has observed:

> *" ... there is perhaps too much emphasis on management and not enough on action in addressing harmful uncertainty".*

This remark is particularly salient in the context of risk management, because until recently the reactive approach dominated, whereby harmful uncertainties were often not addressed at all. The focus of risk management has shifted to the proactive approach, but much remains to be learnt about how we can best tackle harmful uncertainty.

3.5 RVS to Improve Risk Decision-making

Preserving knowledge and experience gained in an organisation is a valuable aspect of the RVS concept. As indicated above, decision-makers often use outside sources of knowledge and information because that is where the data are most easily accessible and are convenient in other ways (e.g. manifest in a consultant who can assist them with the matter to be decided). However, external sources do not have the advantage of reflecting the operating experience and structure of the host organisation.

The idea of preserving knowledge and experience is not new, organisations have always done this. For example, procedures and policies are means of accruing operating experience. Culture also assists this; as Kingston (1996) points out, patterns of behaviour also serve as patterns for behaviour. What is new, however, is that computers allow organisations to preserve and communicate experience more effectively; decision support systems, for instance, provide a means of making this sort of data available to decision-makers in a timely and useful way.

A tool like RVS is not a replacement for devices such as procedures, merely a complementary means of support. Although procedures may suffer from various drawbacks if relied upon as the sole repository of wisdom, organisations have a duty to communicate certain rules derived from legal duties as well as a desire to perpetuate efficient methods of task performance. What a system like RVS hopes to balance is the disadvantageous effect of procedures - of removing variability for ill and for good (such as creative freedom to innovate and to learn). As for culture, RVS allows culture to be communicated more effectively by providing another avenue through which to learn from the experience of other people in the organisation.

As stated, the intention is for RVS to support risk management decision-making. It can accomplish this in several ways. It can help the decision-maker by providing them with more confidence in their facts and understanding of the decision situation, although this is likely to be subject to individual variation owing to culture, technical background and so forth; matters that are discussed in Chapter Two, page 43. Also, a greater availability of data and in a form promotes assimilation, will tend to promote a decision-maker's perception of the range of possibilities that exist for a particular decision. It is to be hoped that, with these improvements, deciding agents can enhance their ability to **execute** actions to implement their decisions. As is clarified in the next chapter, the task of a DSS such as RVS is to support decision-making rather than make and implement decisions automatically.

In line with the arguments presented earlier in this and the previous chapter, it is desirable to extend the family of people who make decisions that explicitly consider risks to people, processes, plant and the environment. The benefit derives from the localisation of decision-making to the people with best access to knowledge about the process, place and technology affected by a change that has happened or is anticipated. The same argument applies to higher level decision-making in such cases, "local" may mean the whole site or whole organisation. What support might be given to members of this extended family to improve their confidence when making decisions with risk management implications?

In order for a person to be a deciding agent, they need to possess a certain power (i.e. confidence and authority) to make decisions. As was mentioned in Chapter Two, Morgan (1997) identifies 14 sources of power, including control of decision processes, and control of knowledge and information. RVS can help the organisation to **control decision processes** and **control knowledge and information** in a number of ways. It can enable the people within the organisation to:

- Collect risk management data from throughout the organisation.
- Store this wealth of risk management data in a meaningful format
- To surf risk management data to extract relevant information to:
  - guide decision-making
  - enrich their mental model of the organisation
- Estimate the possible effects of decisions under consideration
- Present relevant information to influence other decision-makers
- Trace the long-term effects of decisions that are implemented.

These sources of power have a bearing on a person's ability to act as a deciding agent, and their ability to implement a decision that they have made. This is as true of the risk expert as any other decision-maker.

3.6 Summary of Chapter Three

In this chapter the main objective has been to "explore different theoretical perspectives on decision-making and consider their impact upon the informational requirements of decision-makers." In doing so the fourth research objective, to "develop criteria for risk management decision support system (DSS) design" (page 12) has been informed.

What is clear about the decision-making is its complexity. A review of the literature produces the conclusion that our understanding of decision-maker is not developed at a detailed level. However, there is a considerable body of work that operates at a higher level, that is, the level of the black-box of the decision-maker interacting with the black-box of the decision-situation.

Another product of the literature survey is awareness of the need to define what is meant by the key terms. Correspondingly, *decision*, *deciding agent* and *decision-making behaviour* were discussed. For the purposes of this work, *deciding-agent* and *decision-maker* are used interchangeably. Patently important to the present work is to know when someone is likely to use RVS; part of the answer is provided by Selangros (1999). Decision-making behaviour will be engaged in when a person judges that they have the power to act in a situation and perceive the need to choose between alternative actions.

There are three main viewpoints in the literature. The first two of these are referred to as the classical theories: *Normative* and *Descriptive*. Normative theories propose how decision-making **should** occur; Descriptive theories that attempt to describe how decision-making **does** occur. The third perspective, more recently developed than the others mentioned, is the *naturalistic decision-making* viewpoint. NDM attempts to understand the setting of decisions and the constraints that operate upon decision-making in the real-world. NDM is only secondarily concerned with the mechanics of decision-making in, as it were, the black-box.

The classical theories reviewed can be integrated into a five-task view of the decision process (summarised on page 85 in Table 6). RVS will provide unequal support for the five tasks (see Table 7) below.

Decision Tasks	Mode of RVS Support
1. Interpretation of reality	• Widening scope of data search. • Provision of data from sources that are unfamiliar to the decision-maker. • Balancing decision-makers' preference for external sources by enhancing the availability of data from internal sources. • Clarification of issues and objects involved.
2. Select information	• Provide an available source of information that the decision-maker can use in a way that reflects his/her personal style of search and interaction.
3. Orientation / Guidance	• Little contribution (*more the province of expert systems than decisions support systems – discussed further in the next chapter*).
4. Assessment	• As above.
5. Updating	• Not support of decision-maker per se, but some support of the review of the decision.

Table 7. RVS support of the five component tasks within a decision

As indicated in Table 7, RVS could assist the review of the decision probably by someone other than the decision-maker. Whilst not making the mechanics of the decision process transparent, RVS would allow the state of information available at the time of the decision to be reviewed. Whilst the wider set of data the decision-maker relied upon could not be recreated by this means, nonetheless, part of the contemporaneous situation may be revealed.

Naturalistic decision-making is more closely allied to the purposes of DSSs than the classical decision-making theories (these, particularly the normative theories, are more informative to the design of *expert systems* – discussed in the next chapter). NDM research provides a clearer understanding of the kinds of support that a decision-maker might need as well as an indication of the situational constraints to be accommodated in proving that support. NDM makes clear the real-world conditions that decision-makers experience: uncertainty about the goals to served and the data on which to base their decision; a convoluted process featuring feedback loops and poorly structured situations; the need to grapple with complex interplay between elements of their situation and different goals; and, in all of the foregoing, dynamic change during the lifecycle of the decision. RVS needs to accommodate the complexity of the decision-maker's task by providing information in a flexible way and in a form that is easily assimilated. Decision-making is seen as a continuous process of "analysis-decision-action-feedback"; maintaining situational awareness is support role to be accommodated in the design of RVS.

NDM provides a view that seems to reflect the experiences of decision-makers. However, although this face-validity makes NDM useful it is too early to judge its empirical validity. This may be some time in coming as, by its nature, NDM is a real-world rather than laboratory-based approach and this makes experimental data collection very difficult to accomplish. At present, experimental protocols have yet to be developed that deliver reliable evidence of validity whilst accommodating the difficulty of conducting such research outside the laboratory. A useful by-product of DSS technologies is that they may provide a route for collecting data, Silver (1991) suggests that these might help inform theories of decision-making.

Risk management may impose particular properties on decision-making. Not only are there cognitive issues that arise from accounting for low probability events in decision-making, there are also affective aspects; harm and injury are not neutral matters.

An outcome of considering how to support the risk management aspects of decision-making is the need to consider the roles of people in the organisation. In the last thirty years, and particularly the last decade, public policy has moved to a view of localised decision-making as a key ingredient of effective risk management. Organisations vary in the extent to which they have embraced this philosophy and DSS technology can be one means of informing and enabling individuals to integrate the approach into their working lives. The outcome here is a further reminder that the design of RVS needs to accommodate the diversity of decision-makers. The second to the implementation of RVS into the organisation; RVS needs to be advocated within a philosophy that makes it clear to each individual their role in risk management and how RVS can empower them when making decisions. The implementation of RVS also needs to communicate the complementary rather than revolutionary intentions behind RVS.

CHAPTER 4

DECISION SUPPORT SYSTEMS AND INFORMATION VISUALISATION

4.1 Introduction

This chapter considers decision support systems and information visualisation. It lays the foundations for explaining the purpose, design, operation, implementation and evaluation of the RVS software that is the focus of this research. As with the literature on communication and decision making, the literature on decision support systems contains a variety of approaches. This chapter does not aim to provide a comprehensive review of decision support system literature, as such a task would be beyond the scope of this thesis. It instead aims to highlight some of the debates that exist in the literature and to provide the grounding that is necessary to understand the RVS software.

The structure of this chapter is as follows. In section 4.2, the concept of a decision support system is examined, with particular attention paid to the numerous definitions and descriptions that have been proposed by experts in computer science. Next, in section 4.3, there is a discussion of how decision support systems are intended to support managerial decision-making within organisations. Section 4.4 considers the application of DSS to the field of risk management, and examines the fields where decision support systems have been implemented, drawing upon the results of a review of computer science literature and a recent survey of DSS journal articles.

Section 4.5 focuses upon the models of the world that underlie decision support systems, discussing the nature of models, and their advantages and disadvantages. This leads into section 4.6, where the framework of Silver (1991) is presented as a method of describing a decision support system. In section 4.7 a range of risk management models are examined that could form the foundations of a DSS. Finally, in section 4.8, the background to the risk visualisation concept is described, and in section 4.9, the idea of risk visualisation DSS is explored. What can be added to risk management by using a risk visualisation DSS is presented in section 4.10. As in the previous chapters, this one ends with a summary section.

4.2 The Concept of Decision Support Systems (DSS)

The term "Decision Support System" has been used extensively in computer science literature since it was devised by Gorry and Scott Morton in 1971 (Silver, 1991). However, there is no single agreed definition. Instead different researchers and authors each use their own definition, and these definitions vary widely. In this section of the thesis an overview is provided of some of the definitions that have been proposed and ends with a general comment as to how these inform purposes of this research.

Silver (1991) has described DSS in the following way, drawing upon work by Ginzberg and Stohr (1982):

> *"Intuitively, DSS are systems that help managers make decisions in situations where human judgement is an important contributor to the problem-solving process but human information-processing limitations impede decision-making. DSS are an adjunct to the decision-maker, extending his or her capabilities, but not replacing his or her judgement".*

and has provided this formal definition:

> *"A Decision Support System (DSS) is a computer-based information system that affects or is intended to affect how people make decisions".*

The description that Emery (1987), cited by Silver (1991) has provided gives further clarity:

"A decision support system provides computer-based assistance to a human decision maker. This offers the possibility of combining the best capabilities of both humans and computers. A human has an astonishing ability to recognize relevant patterns among many factors involved in a decision, recall from memory relevant information on the basis of obscure and incomplete associations, and exercise subtle judgements. A computer, for its part, is much faster and more accurate than a human in handling massive quantities of data. The goal of a DSS is to supplement the decision powers of the human with the data manipulation capabilities of the computer".

Whilst Gorry and Scott Morton (1971, cited in Turban and Aronson, 1998) have made the following suggestion for a formal definition which mentions the connection between DSS and models - a theme which will be returned to later in this chapter.

"... interactive computer-based systems, which help decision-makers utilize data and models to solve unstructured problems".

Keen and Morton (1978, cited in Turban and Aronson, 1998) have recommended the following formal definition of DSS:

"Decision support systems couple the intellectual resources of individuals with the capabilities of the computer to improve the quality of decisions. It is a computer-based support system for management decision makers who deal with semi-structured problems".

Salvendy (1997) has described a decision-support system in the following way:

"In very general terms, a decision support system (DSS) is a system that supports technological and managerial decision making by assisting in the organization of knowledge about ill-structured, semi structured, or unstructured issues".

Finally, Kleindorfer et al (1993) have provided this definition of a decision support system:

"We shall define a decision support system (DSS) as a computer-oriented resource aimed at aiding decision makers, either by providing better data, quicker access, better models, or more powerful

solutions (in the form of software or consulting). Unlike decision analysis or traditional management science, DSS does not seek to replace the decision maker or take over large chunks of the problem, but instead to supplement or aid. How much aid to offer, and in what form, depend on (1) the problem's complexity, (2) the decision maker's skill, (3) the power of the DSS solution kit, and (4) the organizational context".

The review of computer science literature reveals that there is considerable debate concerning how broadly or narrowly the term 'decision support system' should be defined. There are experts who view a DSS as distinct from computer software like Executive Support Systems, Group Decision Support Systems, Expert Support Systems, Knowledge-Based Management Systems, Management Support Systems, and Idea Processing Systems. There are other experts who class a wide variety of computer software as DSS including statistical software, spreadsheets and expert systems.

For the purpose of this research a broad view of DSS is taken, like that proposed by Silver (1991). However, the intent is to advance beyond traditional DSS research in three ways. Firstly, by showing how the techniques of information visualisation can be used advantageously in decision support systems. Secondly, the "groupware" aspects of DSS are emphasised, particularly the asynchronous communication between people. Thirdly, by developing a DSS for the specialist domain of risk management. As is discussed later in this chapter, risk management is effectively a previously uncharted domain for DSS research.

Day and Kovacs (1996) have used the term 'human-computer-human interaction process (HCHI)' as an alternative to human-to-human information transfer. With RVS, this process is divided in two phases. First, the "filling-up" phase representing the human-to-computer interface (HCI), and second the computer-to-human interface (CHI) as shown in Figure 3.

In this thesis, DSSs are considered as being quite distinct from expert systems. There is research on the application of expert systems to risk management and its focus is considerably different to this research. To aid the distinction, it is worth providing a definition of an expert system (Turban and Aronson, 1998):

> *"Computer system that applies reasoning methodologies on knowledge in a specific domain to render advice or recommendations, much like a human expert. A computer system that achieves a high level of performance in task areas that, for human beings, require years of special education and training".*

From this perspective, expert systems appear to benefit more from the normative theories of decision-making reviewed in the previous chapter and fulfil different decision-making tasks (the tasks of Orientation/Guidance and Assessment in Table 6 on page 85) to those supported by DSS technology.

4.3 How DSS Software Supports Management Decision-making

The attraction of DSS software is that it does not aim to take over management decision-making, or to dictate solutions to management for particular problems, but instead is intended to supplement the decision-making process. The software provides information and tools, which make it easier for a manager to find and analyse data, and it is then the manager who applies judgement and creativity to decide upon solutions. The software, although sophisticated, is an assistant to the human decision-maker. This point is emphasised by McKenna (1994):

> *"A decision support system is a system that provides information to supplement rather than replace managerial decision making".*

The overall goal of decision-support systems is to improve the effectiveness of decision-making within organisations (Salvendy, 1997). By 'effectiveness' it is meant the quality of decision-making. Salvendy has stated:

> *"... Thus, the principal goal of a DSS is improvement in the effectiveness of organizational knowledge users through use of information technology. This is not a simple objective to achieve as has been learned in the process of past DSS design efforts".*

Eom et al (1998) identified the main characteristics of DSS software. They state that it:

- Supports decision makers rather than replaces them
- Utilises data and models
- Solves problems with varying degrees of structure: non structured (unstructured or ill-structured); semi-structured; semi structured and unstructured tasks
- Focuses on the effectiveness rather than the efficiency of decision processes (facilitating decision processes).

This explanation is useful because it again emphasises that DSS are intended to support rather than replace decision-makers, and that the software is based on models. It mentions that DSS software can help to solve problems with varying degrees of structure. This suits risk management where many of the problems that are encountered are semi-structured or unstructured. The final point is particularly relevant, and is similar to the point made by Salvendy (1997), because it stresses that DSS are meant to improve the quality of decision-making ("effectiveness"), not to reduce the financial cost of decision-making ("efficiency").

The concept of DSS software is heavily intertwined with an understanding of decision-making as a complex, dynamic, adaptive and creative process as was discussed in Chapter Three. This can be seen in the following quotations that are made in connection to designing decision support systems.

> *"It is now proposed that no aspect or dimension of the decision making process should be fixed a priori: criteria, alternatives, constraints, measurements, evaluations and representations, all are in continuous flux, all change and all are repeatedly reformulated in search for patterns, wholeness, harmony or cognitive equilibrium".*
>
> Silver (1991)

> *"No aspect of a decision process should be fixed a priori because decisions emerge as 'harmonious' patterns balancing the different decisional components (such as criteria, alternatives, and constraints). There is less of a need to model human thinking by logical rules and algorithms and more of an emphasis on providing a flexible decision environment with the ability to capture 'habit of mind' (patterns) conditioned on specific contextual knowledge. A focus on learning in decision-making has the most value for unstructured problems in dynamic decision environments. It is also necessary to have skilled end users and an organizational decision environment that is flexible and encourages innovation".*
>
> Dutta et al (1997)

Sauter (1999) suggests that it is not enough for decision support systems to just provide the answer to problems, as would be the case with a conventional expert system. Instead, DSS need to assist decision-makers in three distinct ways. Firstly, they should help decision-makers to understand what they already know. They should help decision-makers to pre-digest information by giving them prepared analyses and additional details about the issue at hand. This first point correlates with the reactive phase of risk management. For example, a DSS could help a risk manager to identify the range of hazards within their organisation and to calculate the number of related incidents during a certain time period.

Secondly, DSS need to help decision-makers to understand the underlying assumptions that are related to the issue, by giving them enough appropriate information, but making sure that they are not overloaded with unnecessary or unwanted details. This connects with the discussion in Chapter Two concerning the dangers of information overload and the limitations implied by "bounded rationality". So DSS need to provide the decision-maker with pre-defined information and analyses, as well as the ability to develop their own analyses after initial guidance. Sauter (1999) believes that this allows "*unknowledgeable decision-makers to explore the decision environment and allows knowledgeable users to pursue subtle clues*". This second point correlates with the proactive phase of risk management. For example, when a risk manager identifies a potential deviation in the risk management system, they need to expand their knowledge and understanding in order to develop suitable preventive plans. A DSS could help them to search for information about similar circumstances that were encountered at the organisation or other organisations in the past, and examine the findings of recent audits, inspections and reviews.

Finally, DSS must help decision-makers to test assumptions, particularly those that differ from pre-conceived ideas. It should also enhance the decision-makers ability to recognise trends. As Sauter (1999) has remarked:

> *"They can illuminate how a current context is similar to one faced previously, and why similar strategies might work; or they can help decision-makers to understand why the current context is different, and therefore why different strategies might work".*

This point correlates to an anticipative phase in risk management. For example, with RVS DSS, a decision-maker could anticipate the likely consequences and costs of a particular recommendation concerning the implementation of new control measures for a specific hazard. Similarly, they could use RVS to anticipate the evolution of a specific risk management problem and to identify future trends by 'surfing' on the picture database for data relating to other hazards. Data will be collected and stored in the picture database within RVS concerning the daily activities of employees throughout the organisation. RVS will record reactive data in relation to past incidents and proactive information, such as findings from inspections or audits. The intention is for RVS to capture the perceptions of a large number of employees regarding possible deviations. The aim is to enhance the risk manager's perception of possible deviations in the risk management system. The goal is to help the risk manager to see new patterns in risk management data and, ultimately, for decision-makers to improve their understanding of the risk related aspects of the situation that they are considering.

4.4 The Application of DSS to Risk Management

As was discussed in Chapters Two and Three, communication and decision-making are crucial aspects of risk management. Risk management essentially involves collecting data, analysing it, identifying problems, applying problem-solving techniques, developing creative solutions, implementing and monitoring the effects of those solutions. At ESA, and similar large multi-national organisations, it is necessary for people from different cultural backgrounds located across different sites in a number of countries to develop a shared understanding of risk management. This necessitates high quality methods of communication. It is a point that will be returned to shortly in a discussion of the 'models' that underlie DSS.

Decision support systems are a tool that can be address some of the challenges that risk management presents to organisations. In theory, a well-designed risk management DSS could help to improve both communication and decision-making. It could offer a means by which organisations can take responsibility for risk management, and attempt to make more effective use of the mass of risk management data that they generate. It is worth noting that according to research conducted by IBM, an average business only uses 7% of the data that it creates (see Figure 4) (IBM, 1996). Meaningful information is never extracted from the remaining 93% of data that is gathered and stored. It is unlikely that risk management data are any less prone to this effect.

Figure 4. Data retrieval (IBM, 1996)

Despite the possible benefits of DSS for risk management, after an intensive review of risk management and computer science literature, it is apparent that there has been very little focus upon the development of DSS in the field, other than the occasional article concerning expert systems or healthcare systems. This is probably due to several reasons. Firstly, as mentioned in Chapter three, the vision of a safety management system in an organisation is often ill-defined and therefore is not communicated effectively with employees. Secondly, it is extremely difficult to collect and represent risk management data concerning deviations. Thirdly, it is only recently that information technology has advanced to the point where it is possible to use information visualisation techniques to represent adequately the collected risk management data.

Unfortunately, it is not possible to give a definitive account of the variety of fields in which DSS *have been developed*. This is because only a small percentage of the DSS that are developed are described in published academic literature. Nevertheless, it is useful to mention a survey by Eom et al (1998) of DSS articles published in academic journals from 1988-1994. They show that in the last two decades there has been a substantial increase in the number of articles published in this area. As is shown in Table 8, the authors split their findings into articles concerning DSS designed for corporate functional management areas and those designed for non-corporate areas. The only reference that is made to risk management is in the non-corporate government area, where there is mention of a cost-benefit-risk analysis of safety for nuclear power reactor and a planning nuclear emergency evacuation applications. The vast majority of DSS software has been designed to support decision making in traditional areas such as management, finance, production, marketing, and education.

Table 8. Decision support systems classification by areas (Eom et al, 1998)

Eom et al (1998) express enthusiasm for the benefits that might be gained from the emergence of new DSS tools such as "Visual Interactive Modelling". Their enthusiasm is endorsed by Loy (1991) who found that the "*user ability to create* *and use visual images is positively related to better problem-solving and problem-structuring performance*". Eom et al (1998) observed that "*the urgent challenge in the DSS field is bridging the gap between practitioners and DSS researchers*". This was another motivation behind the attempt to create risk visualisation DSS software to support risk management decision-making. A primary concern of the research was to make sure that the RVS DSS meets the needs of risk management decision-makers in a large, multi-national organisation like ESA.

4.5 The Models Behind DSS

Behind every DSS is a model of the subject domain with which it is concerned. Therefore, to create a DSS to aid risk management decision-making, it is first necessary to develop a model of risk management on which the software is to be based. This is not easy, as risk management is an extremely complex endeavour. All too often models of risk management are developed that are far too simple and restrictive. This is evident in conventional proprietary health and safety management software, where many of the computer programs are based on very limited or poor models of health and safety management (Barker, 1998). These conventional programs tend to lose sight of many of the most important aspects of risk management, such as the need to be flexible, adaptive, dynamic, responsive and creative. We have visited this issue before as an example of the problems of "organised complexity"; picking up this theme, Casti (1997) has argued strongly that the full complexity of systems needs to be recognised when models are developed to represent them.

> *"Complex system pervades every nook and cranny of daily life, from the patterns of traffic in urban transport networks to the movement of prices on financial markets. The processes are fundamentally different from the simple systems that have constituted the focus of the scientific enterprise since the time of Newton. Simple systems generally involve a small number of individual elements with relatively weak interactions between them, or they are systems like enclosed gases or distant galaxies, composed of such vast numbers of objects that can employ statistical averaging techniques to study their behaviour. Complex systems, on the other hand, involve a*

medium-sized number of agents: drivers, traders, molecules ... Moreover, in complex systems the agents are generally both intelligent and adaptative, in the sense that they make decisions in accordance with various rules, and are ready to modify their rules of action on the basis of new information that comes their way. There are no dictators or centralized controllers in the systems; no single driver, so the agents in a complex system make their decisions and update their rules for action on the basis of local, rather than global, information".

For the purposes of this research, it is necessary to consider three fundamental questions: (1) What is a model? (2) What are the advantages and disadvantages of models? and (3) How can computer technology improve our ability to create and experiment with models?. The domain of models is very broad so only an overview is given of models as a way of sharing visions in risk management.

4.5.1 What is a model?

Previous discussion of models (in Chapter Two) has focussed of them as an essential part of communication. Here, we are primarily interested in models as frameworks around to build decision support systems. Shneiderman (1998) points to the need for the models implicit in software to be compatible with the mental models of users.

A model is a representation of the world or some aspect of it. There are many definitions of the term 'model' in psychology and computer science literature, including the one offered by Turban and Aronson (1998):

> *"A model is a simplified representation or abstraction of reality. It is usually simplified because reality is too complex to copy exactly and because much of the complexity is actually irrelevant in solving the specific problem".*

A model can vary in its level of complexity and accuracy depending upon its purpose and upon the knowledge, experience and perceptions of the individual(s) who created it. A model can be internal or external. An internal model is often referred to as a "mental model" in psychology literature; it is a representation that an individual holds in long-term memory concerning the way that a particular object, concept or system works. For example, an individual may have a mental model of how a car engine works. Depending upon the individual, this model may be more or less accurate, and may have more or less detail. Norman (1986) provides the following definition of a mental model:

> *"The model people have of themselves, others, the environment, and the things with which they interact. People form mental models through experience, training and instruction".*

An external model is an external representation of the way that the individual(s) believe that a particular object, concept or system works. For example, an individual may draw a flow chart to represent how the economy works, or build a scale model to represent the dimensions and design of a ship, or create a computer program to represent an aspect of human cognition.

Models are vital to communicating meaning. Chapter Two has already introduced the concepts of perception and communication from a mechanistic perspective. However, cultural and psychological aspects are strongly implicated in the use of models to communicate. This point is argued by Kingston (1996) who quotes Espejo and Harden (1989):

> *"Let us be clear about this. A model is a convention-a way of talking about something in a manner that is understandable and useful in a community of observers. It is not a description of reality, but a tool in terms of which a group of observers in a society handle the reality they find themselves interacting with. But whatsoever, an individual may never communicate what is accessed to another individual except in terms of models. This is not a limitation, but is precisely the motor for the generation of a consensual domain. A consensual domain is none other than the play of a particular set of interacting models."*

There are many different types of model that can be used to represent aspects of the world. Casti (1997) identifies four basic types of models (experimental, logical, mathematical/computational, and theoretical), which can be used in three different ways (predictive, explanatory and prescriptive). He has produced guidance concerning the characteristics that allow a good model to be distinguished from a bad model. This guidance suggests that a good model should capture the essence of its subject. So the model has to be rich enough to allow us to ask the questions that we want to ask about the subject that the model represents, and to be able to provide us with the answers. Further, a good model is one that gives us the ability to predict what the real system will do next. In other words, it should ideally be able to both explain the system which it represents with sufficient richness, and be able to predict its future.

Other characteristics that Casti (1997) identifies as belonging to a good model are simplicity, clarity, bias-free and tractability. A model should be as simple as possible. It should contain only what is necessary in order to provide the explanation of the system which is required, and to provide answers to the questions that need to be asked. A model should be clear, so that it can be understood and used to produce the same results by different people. A model should be objective so as to be independent of investigator bias. Finally, a model should be designed so that it is tractable - so that we can afford the costs that are involved in obtaining answers from the model.

Figure 5. Scottish Hydro-electric money flow (Scottish Hydro-electric, 1998)

Figure 6. New Horizons and Opportunities (Scottish Hydro-electric, 1998)

The examples in Figures 5 and 6 show how Scottish Hydro-electrical use models to explain the operation of their organisation. There are two main reasons behind their use of the illustrated models. The first reason is to improve employees' understanding of the organisation. In each meeting room within the organisation, the models are displayed as posters and staff are easily able to visualise the work process as well as the possible effects of their decisions on one or more parts of the organisation. The second reason is to improve customers' understanding regarding the costs of the products provided. The external models allow employees to develop a shared mental model of the organisation, which in turn makes it easier for them to communicate about the organisation.

4.5.2 Microworlds

Senge (1990) has developed the concept of 'microworlds' - computer-based models of aspects of the world that can be manipulated and experimented with by a decision-maker. According to Senge (1990) "Human beings learn best through first-hand experience". So, for example, a person learns to walk, drive a car, and write a letter by trial and error, which means that they "*act, observe the consequences of [their] action and adjust*". Senge (1990) calls this "*learning by doing*", and observes that although it is the ideal way of learning, in the technological age it is not always possible because with complex systems the consequences of our actions may not be immediate or unambiguous, and may be distant in time and space. Senge (1990) comments:

> *"... we learn best from experience, but we never experience the consequences of our most important decisions. How, then, can we learn?"*

Senge (1990) has a vision of microworlds:

> *"Microworlds enable managers and management teams to begin "learning through doing" about the most important systemic issues. In particular, microworlds "compress time and space" so that it becomes possible to experiment and to learn when the consequences of our decisions are in the future".*

Microworlds are advanced game systems where managers can learn by trial-and-error in a safe environment; this approach is well known by the new generation of young managers who have grown up playing with computer games consoles like Nintendo. Their mental model is more flexible in this sense because they know the advantages of repeatedly playing a game with different starting parameters, so for them the concept of microworlds will be just be a transfer from playing games for leisure to playing games for business. With microworlds managers can test: what will happen if we implement this recommendation, and what will be the impact if we do this or this.

In the future it may be possible to use microworlds to test risk management decisions. For example, a decision to implement a new health and safety policy, or a decision to invest in new fire protection equipment. However, at the moment the idea of microworlds is futuristic, and they require extremely powerful computer hardware and software for development. Further research needs to be undertaken to investigate the feasibility and implications of microworlds as a means of enhancing organisational learning and management decision-making. Senge (1990) has commented:

> *"We still have a long way to go before "practice fields for management teams" are a way of life in learning organizations. But important principles and tools are emerging that are pointing the way".*

4.5.3 The advantages and disadvantages of models

Turban and Aronson (1998) have identified a number of benefits of using models. These are as follows:

- *Models enable the compression of time. Years of operations can be simulated in minutes or seconds of computer time.*
- *Model manipulation (changing decision variables or the environment) is much easier than manipulating the real system. Experimentation is therefore easier to conduct and does not interfere with the daily operation of the organization.*
- *The cost of modelling analysis is much less than the cost of a similar experiment conducted on a real system.*
- *The cost of making mistakes during a trial-and-error experiment is much less when models are used rather than real systems.*
- *Today's environment involves considerable uncertainty. With modelling, a manager can calculate the risks involved in specific actions.*
- *The use of mathematical models enables the analysis of a very large, sometimes infinite number of possible solutions. With today's advanced technology and communications, managers often have a large number of alternatives from which to choose.*
- *Models enhance and reinforce learning and training.*

Royal Dutch/Shell was one of the first large organisations to recognise the influence of employees' mental models of the organisation, the market, and the competition. Senge (1990) suggests that by bringing these mental models to the surface so that they could they be examined and changed was one of the ingredients in Shell's success, advancing from being the weakest of the big seven oil companies to being the strongest.

Morgan (1997) uses cybernetics theory to propose his view of current guidelines for learning of organisations. He suggests that for organisations to learn they must develop the capacity to do the following:

1. *Scan and anticipate change in the wider environment to detect significant variations.*
2. *Develop an ability to question, challenge and change operating norms and assumptions.*
3. *Allow an appropriate strategic direction and pattern of organization to emerge.*

These points are particularly useful for highlighting the ways that RVS can enhance organisational learning as well as provide support to decision-makers. The first point concerns finding "*ways of inventing completely new ways of seeing their environment*" (Morgan, 1997). This point matches the fundamental concept of risk visualisation that underlies RVS remarkably well. It is a point that will be returned to later in this chapter when information visualisation and risk visualisation are discussed in greater detail. Morgan continues to say that:

> *"[Organisations] need to be able to create appropriate maps of the reality with which they have to deal. But the process has to be active rather than passive. It has to embrace views of potential futures as well as the present and the past".*

Although Morgan uses the term "maps" it is similar to the idea of mental models, and the term "reality" is similar to the idea of the first degree of reality, which was discussed in Chapter Two. Morgan goes on to say:

> *"Intelligent learning systems use information about the present to ground their activities in a business reality. But they are also skilled in spotting the "fracture lines", signals, and trends that point to future possibilities. They are skilled at imagining and anticipating possible futures and acting in the present in ways that help make those futures realities. Often, the skill is not just cognitive but intuitive, emotional, and tactile as well".*

As has been emphasised throughout this thesis, one of the central aims of RVS is to enhance the risk manager's ability to identify 'fracture lines', or in risk management terms 'latent failures', and in systems theory terms 'deviations' or 'bifurcations'. It is intriguing to find that the need to develop effective tools to identify early deviations exists across different disciplines such as business management, risk management and systems theory. The previous quotation from Morgan (1997) mentioned the need for these tools to provide the user with the means to **anticipate** possible futures. This is a theme that will be returned to later in the thesis. Senge (1990) states that it is necessary to design these tools to include a certain freedom so that the user can still apply the richness and creativity of intuition.

There are not only advantages associated with the use of models. Beer (1997) has identified the following disadvantages:

> *"I am speaking quite simply about the image of something that we hold in our minds-the idea we selected from myriad sensory impressions, endowed with coherence, and elected to call 'reality'. These **models** are not systemic. Worst still, they are flawed in two other ways. Firstly, they are **oversimplifications** in cybernetic terms, they do not exhibit the requisite variety. Secondly, they are usually **out-of-date**".*

The points that Beer (1997) raises have important implications for the design of the RVS software. It is hoped that the design of RVS will be able to overcome to some extent the possibility of the software providing an oversimplified and out-of-date model of risk management within an organisation. This is because the RVS software is designed to give the user the ability to perceive multiple realities of the first degree, as was discussed in Chapter Two. This is made possible by having a large number of people participate in creating the data that is input into the RVS database. Similarly, because RVS is intended to operate via an organisation's intranet, the database can be updated constantly by the multiple participants who are based throughout the organisation. The data that is stored within the RVS database, and the model of risk management within the organisation that the software provides, will thus always be fresh. One of the greatest challenges of this research was to attempt to design risk management computer software that can allow this type of multiple user participation.

4.5.4 Using computer technology to create models

With computer technology it is possible to design software that provides us with models of particular subjects. This is a vast area, and has already been touched upon in the discussion of microworlds. It would be impossible to describe all of the research that has been conducted here, for a detailed analysis the reader is referred to Casti (1997) who has described a variety of models that have been created using computer technology. Later in this chapter, and also in Chapter Five, we will examine how risk visualisation provides a model of risk management that the risk manager can explore, manipulate and experiment with. For now, one example will be outlined to show how computer technology can be used to create models with which people can experiment.

The example concerns real-time weather forecasting during the flight of aeroplanes. This idea is being developed currently by a friend who works for air traffic control. It involves the application of space technology. Traditionally, in order to guide the flight of aeroplanes, a weather-forecasting model is created from data acquired from ground stations and satellites. This model can be used to predict and inform pilots of changes in weather conditions during flight.

The new idea involves installing laser sensors on each commercial aircraft. These sensors will measure in real-time the physical weather that is local to the aircraft, for example, wind, temperature, pressure, and water vapour. This data will be communicated to a satellite in real-time, and downloaded to a ground station to build a computer model of the weather conditions. As before, this model will be used to predict and inform pilots of changes in weather conditions during flight. The advantage of the new technique is that the weather-forecasting model is refined continuously with fresh, local data. It should therefore be far more accurate and up-to-date. This example shows how new computer technology can be applied creatively to allow us to improve upon traditional models.

4.6 The Design of a DSS

Just as there are many definitions of DSS, there are similarly many frameworks for designing a DSS. For the purposes of this research, the framework proposed by Silver (1991) has been selected as the most valuable means of describing the basis of a DSS. In this section, there will first be a consideration of how to determine what a DSS should be designed to support and how it should provide support. Then Silver's DSS framework will be examined. This will provide the foundations for understanding the RVS DSS.

4.6.1 What and How to Support ?

The first questions that have to be addressed when designing a DSS are:

- What is the DSS to support ?
- How is the DSS to provide this support ?

Dutta et al (1997) developed a decision-support system for marketing and created a model to illustrate the interaction between different possible modes and objects of decision support (see Figure 7).

The model has two axes along which a DSS can be positioned. At one extreme a DSS can be designed to automate tasks and produce outcomes. This is similar to conventional proprietary health and safety management software that is restricted in its functions and flexibility (Barker, 1998). Dutta et al (1997) label this type of DSS software as "restrictive" because it can only offer limited support to decision-making. For example, in risk management, proprietary health and safety management software is often designed with the purpose of calculating audit results or producing tables of incident statistics.

Figure 7. Modes and Objects of Decision Support (Dutta et al, 1997)

A more advanced type of DSS software is able to 'informate', that is, to "*capture and provide information about organizations*" (Dutta et al, 1997). It is intended to create and provide information related to the decision and the decision-making process. It differs from restrictive DSS software because it focuses on the process of decision-making rather than just on producing an outcome. Dutta et al label this as "Guiding" DSS software.

User controlled flexibility is a long-standing criterion for a user-centred approach to software design (Shneiderman, 1998). Dutta et al (1997) label the most advanced type of DSS software as "Customisable". This software is able to stimulate the user to learn and be innovative, and emphasises improving both the decision and decision process. The aim of this research is for the RVS DSS to fall into the latter category because of its design based on the concept of risk visualisation that is underpinned by a theoretical understanding of communication, perception, decision-making and organisational learning.

4.6.2 A framework for understanding DSS

As a starting point, it is useful to consider the purpose of the DSS framework of Silver (1991):

> *"The framework is not a framework for developing DSS, for using DSS, for evaluating DSS, or for classifying DSS. It is a framework for understanding DSS. .... It is a way of organizing the knowledge necessary for comprehending the complex world of computer-based decision support".*

According to this framework, to understand a DSS it is necessary to examine three interrelated areas. These are Underlying Technologies (UT), DSS Lifecycle Processes (LC) and Substantive Decision Support (DS) (see Figure 8).

Figure 8. The Three Areas of Decision Support System (Silver, 1991)

Each area is described briefly below.

4.6.2.1 Underlying Technologies (UT)

In Silver's framework, the underlying technologies of a DSS are:

- *Basic Technologies*
- *Development Systems*
- *Delivery Systems (platforms)*
- *System Architectures (internal views)*

'Basic technologies' refers to what the designers of a DSS draw upon from the fields of computer science and management science to inform the creative process. For example, many DSS designers utilise the concept and technology of the computer database. 'Development systems' refers to the computer programming languages and tools that the software designers use to produce a DSS. 'Delivery systems' refers to the computer hardware that supports the DSS, and 'system architectures' refers to the internal structure of the DSS.

4.6.2.2 DSS Lifecycle Processes (LC)

According to Silver's framework, DSS Lifecycle Processes refer to the different steps in the lifecycle of a DSS, from the initial idea to the system eventually becoming obsolete and being decommissioned. Silver divides the lifecycle process into eight overlapping phases:

- *Systems analysis*
- *Design*
- *Construction*
- *Implementation*
- *Training*
- *Use*
- *Evaluation*
- *Evolution*

Silver (1991) comments that with DSS "development and use are often intertwined, with short feedback cycles and frequent iteration through activities as the system evolves over time". Silver states that systems analysis, design, construction and evolution can be thought of as the building process for a DSS. The design process is continuous:

> *"DSS designs are generally not static; DSS evolve over time in response to changes in decision makers, in organizational settings, in tasks, and, most importantly, in perceptions of tasks by decision makers".*

Implementation of a DSS refers to putting the DSS to use in the workplace and involves many behavioural and organisational issues. Training refers to the need to train users how to use the DSS software. Use requires consideration of who are the DSS users, and when and how the DSS is to be used within an organisation. Finally, evaluation refers to the need to evaluate a DSS throughout its lifecycle. Unfortunately it is not easy to evaluate a DSS, because it is difficult to measure whether or not it has improved the effectiveness of decision-making.

4.6.2.3 Substantive Decision Support (SDS)

In Silver's framework, Substantive Decision Support concerns understanding decision-making processes, computer systems to aid decision-making, and the way computer decision support systems affect decision-making. It consists of:

- *Effects on decision-making processes*
- *Decision-making needs*
- *Computer-based decision aids*
- *Decision-making environments*
- *Characteristics of DSS*

'Effects on decision making processes' refers to "how computer-based systems can and do affect the decision-making processes of their users". 'Decision making needs' and 'decision aids' refers to the need for DSS designers to identify the needs of decision-makers and develop a DSS that can address these needs. Silver (1991) has suggested that decision-makers may need a DSS to help them with several common decision-making needs:

- *Fuller/better exploration of alternatives*
- *Earlier/better detection of problems and opportunities*
- *Coping with multiple or undefined objectives*
- *More explicit treatment of risk and uncertainty*
- *Reducing systematic cognitive biases*
- *Creativity*
- *Communication, co-ordination and consistency*
- *Structuring the decision-making process*
- *Learning*

A DSS must always be tested to make sure that it satisfies the needs of decision-makers and does not "*cause undesirable side-effects*" (Silver, 1991). Silver (1991) uses the phrase 'decision-making environment' to refer to:

- *The people who participate in the decision-making process*
- *The problem-solving tasks they confront*
- *The organizational or societal settings within which they operate*

Silver (1991) states that decision-making environments are idiosyncratic and dynamic, with decision-makers, tasks and settings all changing with time. Lastly, 'characteristics of DSS' refers to the distinctive features of a DSS, which make it different from other DSS. Silver argues that in order to identify the distinctive features of a DSS, the software needs to be described in terms of functional capabilities, how the capabilities aid decision-making needs, how the DSS appears to the user, and how the DSS influences decision-making. Essentially, there needs to be a clear recognition of what a DSS is able to do and what it is not able to do.

4.7 Models in Risk Management

The role of models in the design of decision support systems has been introduced in section 4.5. Here, the more specific issue of the model to be used in RVS, is discussed.

To be able to develop a DSS for risk management, a suitable model of risk management is first needed to form its basis. Over the last hundred years, a large number of models have been proposed in the field of risk management. Some aim to represent risk management as a whole, whilst others aim to represent particular aspects of risk management such as accident causation, problem-solving and risk-taking behaviour. Inevitably, the choice of model for RVS is restricted by the need to reflect the model used in the host organisation - ESA. However, to assist the generalisation of this research to risk management, the relationship between the ESA model and the models established in the risk management literature, is discussed. The ESTEC Safety Management System Model has been used as the underlying model for the RVS DSS; this is presented last.

There is no single definitive model of risk management in the existing literature, but that there are instead a varied assortment of models that each offer particular insights and carry certain strengths and weaknesses. It is important to recognise that a risk management model can:

- Be simple as well as complicated
- Provide the foundations for the creation of other models
- Be designed to serve different purposes
- Prompt risk managers to create their own organisation-specific models.

4.7.1 BS8800 occupational health and safety management systems model

In Great Britain one of the latest risk management models is that within BS8800: Occupational Health and Safety Management Systems (BSI, 1996). This model is shown in Figure 9. It attempts to provide an overview of the proactive risk management process. Each stage within the model is broken down into further detailed description. The model provides a good starting point for understanding the nature of risk management.

However, a significant problem is that the focus is solely upon the nature of each element within the system, with little or no attention paid to the links between the elements. Thus the model represents risk management as a simplified linear process - a block diagram where each stage is completed in turn. This does not provide a good representation of risk management in the real world, where there is considerable crossover and inter-linking between the elements displayed in the BS8800 model. Indeed, as was mentioned in Chapter One, it is often the links between the elements that are the most important in terms of the success of a risk management system.

Figure 9. BS8800 OHSM Systems Model (BSI, 1996)

4.7.2 Barrier analysis structure model

The Barrier Analysis Structure Model is very basic but serves as the foundation for many other risk management theories and models (see Figure 10). The model is presented in Kirwan (1994) but is based on the cited work of Haddon (1973) and Trost and Nertney (1985). We can have a series of models and though each model is incomplete, each one is like a brick allowing us to build a wall when they are used together, so building up our understanding by looking at many different models.

Figure 10. Barrier analysis structure model (Kirwan, 1994)

4.7.3 Organisational accident causation model

The Organisational Accident Causation Model (Reason, 1995) has a strong connection with the RVS research (see Figure 11). Sometimes a model's value comes from its ability to help an individual to visualise and understand a concept or a topic that they had previously thought about but were unable to grasp fully. This model helped to inspire and shape my personal vision of risk management, and provide impetus for the research.

Figure 11. Organisational Accident Causation Model (Reason, 1995)

The model addresses the question of how risk managers can detect latent failures and it generates a broad research horizon. According to Reason (1995) latent failures are important because:

> *"... all technological systems are not only operated by human beings, they are also designed, constructed, organized, managed, maintained and regulated by them as well".*

4.7.4 ESTEC safety management system model

Everyone is able to create their own view about how risk management should be structured in their organisation. At ESTEC, over the last decade, I have created, revised and used a risk management model. This is the ESTEC Safety Management System Model (See Figure 12). In my role as a risk manager, I often use the model to explain to people what ESTEC are doing to manage risk and for what reasons. The model was the starting point that inspired my ambition to conduct this research.

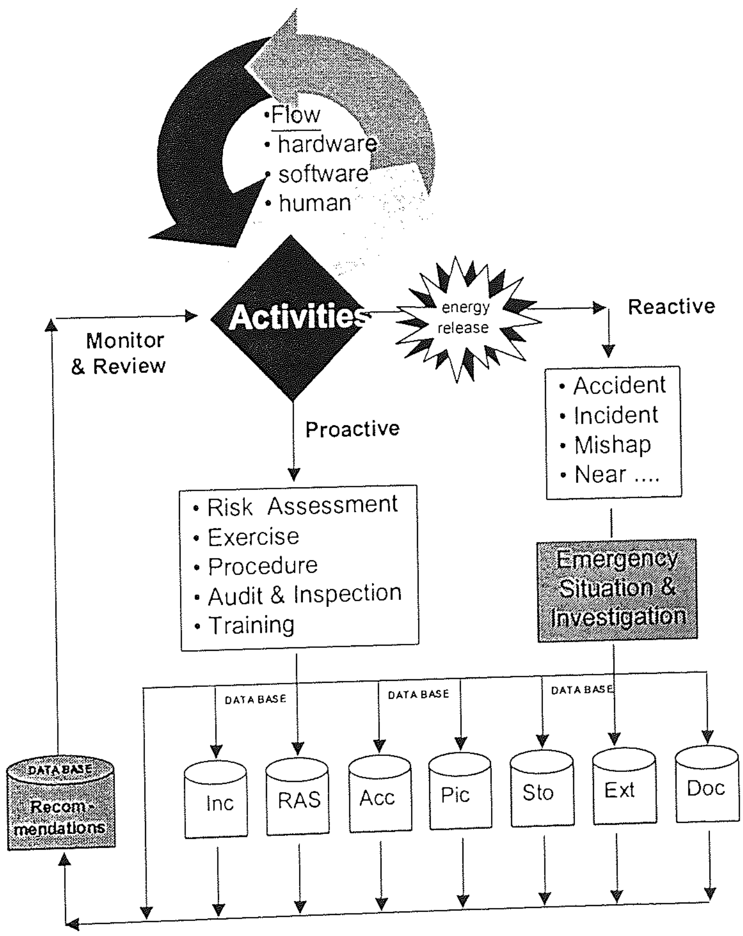


Figure 12. ESTEC safety management system model

Although experts in risk management may criticise the structure and contents of the model, the reason for presenting it here is to demonstrate how an individual risk manager can develop a model to represent their own understanding and vision of risk management. The risk manager can then use this model to share their vision with others within the organisation. It can be used in a constructive way to elicit the understanding and participation of employees.

A quick description of this model is provided here. The basic orientation of the model derives from Reason (see section 4.7.3) insofar as the view is of a socio-technical system in which latent failure and active failure interact to produce accidents and other bad outcomes.

Starting at the top of the model, an organisation combines hardware, software and human resources to undertake a range of activities. The activities require the use of controlled energy. Occasionally, there may be an uncontrolled release of energy. This may result in an accident or incident if suitable preventive measures are not in place or if they fail. The concept of organisational activities requiring the use of controlled energy and accidents and incidents occurring when there is an uncontrolled release of energy is **drawn from the Energy Barrier Analysis model** that was described earlier (see Figure 10).

When an accident or incident occurs, the organisation needs to make an emergency response and then investigate the underlying causes. Incident and accident data is collected to store in the organisation's Incident and Accident databases. Photographs are taken of the accident or incident site, and these are stored in the organisation's Picture database. Documents are gathered from meetings concerning the incident or accident, and these are stored in the organisation's Documents database. This is the reactive element of risk management.

The proactive element of risk management is represented in the middle of the model. **This element is the first connection between BS8800 and the ESTEC model.** Risk assessments, audits, inspections, training, procedures and exercises are undertaken. Data is collected concerning these and is stored in the organisation's associated databases. For example, risk assessment findings are stored in the Risk Assessment Studies database and photographs are taken during risk assessments to store in the Pictures database. Suggestions and scenarios are stored in the Stories database, whilst risk management events in other organisations are stored in the External database. The risk manager uses the data that is stored in the seven databases to devise recommendations that are recorded in the Recommendations database. Recommendations are implemented, monitored and reviewed. This creates a continuous feedback and improvement cycle. **Monitoring and review, is the second point of connection between BS8800 and the ESTEC model.**

In both the reactive and proactive modes, it is essential that the organisation learns from what occurs. As has been emphasised throughout this thesis, a learning organisation is better able to survive in a dynamic environment. With RVS an organisation can store what they learn in the databases. The design of the databases is described in detail in Chapter Five.

4.8 The Concept of Risk Visualisation

This research is based upon new ideas concerning how we can make it easier for risk managers to see bifurcations within an organisation at an early stage and so be able to remove them from the system before an incident results. This forms the basis of the concept of risk visualisation.

4.8.1 Information visualisation

The original idea for risk visualisation was to apply sophisticated information visualisation techniques (also known as data visualisation) to risk management information. Card and Shneiderman (1999) introduce the idea of information visualisation as follows:

> *"Advances in science and commerce have often been characterized by inventions that allowed people to see old things in new ways. Telescope, microscope, and oscilloscope are obvious instrument examples. But invented visual representations, such as maps, statistical diagrams, and PERT charts, also qualify. Computers can combine both new instrument*

and new visual representation, resulting in the emerging field of information visualization".

Also

"In the next period, information visualization will pass out of the realm of an exotic research specialty and into the mainstream of user interface and application design. There will be a shower of products using its techniques. It especially seems likely that techniques from information visualization will be important in creating interfaces to large-scale databases and document collections, most notably applications, services, and electronic commerce for the Internet and its successors".

Turban and Aronson (1998) have described data visualisation in the following way:

"Data visualisation refers to technologies that support visualization of information. It includes digital images, geographical information systems, graphical user interfaces, multidimensions, tables and graphs, virtual reality, 3-D presentations, and animation. Visualization software packages offer users capabilities for self-guided exploration and visual analysis of large amounts of data. People have reported that by using visual analysis technologies, they have spotted problems that have gone undetected for years".

Although the last line of the above quotation is not based on scientific research findings, it does raise the question of to what extent data visualisation techniques can help people to see problems that they may otherwise fail to observe when relying on conventional methods alone. The verbal feedback to computer science experts suggests that data visualisation techniques may help. Turban and Aronson (1998) expand on this by stating that data visualisation:

"... uses color, form, motion, and depth to present masses of data in a comprehensible way".

Before providing an example from Massachusetts Institute of Technology (MIT) where a data visualisation program has been created for financial management where a person can:

"... use a mouse to "fly" over a 3-D landscape representing the risk, return, and liquidity of a company's assets. With practice, ... [they] can begin to zero in on the choicest spot on the 3-D landscape: the one where the trade-off among risk, return, and liquidity is most beneficial".

Norman has observed how external aids can enhance cognition, and information visualisation software can be considered as such an external aid (Card and Shneiderman, 1999):

"The power of the unaided mind is highly overrated. Without external aids, memory, thought, and reasoning are all constrained. But human intelligence is highly flexible and adaptive, superb at inventing procedures and objects that overcome its own limits. The real powers come from devising external aids that enhance cognitive abilities. How have we increased memory, thought, and reasoning? By the invention of external aids: it is things that make us smart".

The idea that information visualisation can be an external aid to cognition is emphasised in Card and Shneiderman's (1999) definition of the term:

"The use of computer-supported, interactive, visual representations of abstract data to amplify cognition".

Card and Shneiderman (1999) have gone further to provide a table of research findings that demonstrate how information visualisation can amplify cognition (see Table 9).

As a final comment, Card and Shneiderman (1999) have said about information visualisation:

"The definition of information visualization stresses three goals: discovery, decision making, and explanation. Powerful visual tools can support discovery; Galileo's telescope enabled him to discover the moons of Jupiter, and microscopes revealed the structure of cells. Now, information visualization tools are supporting drug discovery by pharmaceutical researchers and credit card fraud detection by financial analysts. Visual data mining complements the algorithmic approaches for exploring data warehouses. Surprising patterns that appear in data sets can sometimes be found by algorithms, but visual presentations can lead to deeper understanding and novel hypotheses".

Table 9. How information visualisation amplifies cognition
(Card and Shneiderman, 1999)

4.8.2 Risk visualisation

The idea of risk visualisation, which is the focus of this thesis, was heavily influenced by the research of Thomas (1995). Thomas developed a technique for representing information in a three-dimensional format where colour, form and depth were used extensively.

Figure 13 and Figure 14 show examples of this. I was interested in the possibility of representing risk management data in this manner. As an example, incident data could be represented in the format illustrated in Figure 13, with the map representing different locations within an organisation, and the "mountain" heights representing the number of incidents, which had been experienced in each location over the last year. A high number of incidents in one location would result in a high "mountain". The risk manager could easily and quickly survey such a data visualisation map to identify the locations, which have particularly high incident rates. They would be able to gain a rapid overview of a large quantity of information. Other types of risk management data could be represented similarly, such as the levels of risk arising from different hazards within an organisation. Further creative ideas on how to represent data can be found in Card and Shneiderman (1999).

Unfortunately, it is not feasible at the present time to apply Thomas' information visualisation techniques to risk management. There are two main reasons for this. Firstly, because of the elaborate computer hardware and specialist computer programming expertise that would be required, as well as the substantial time and costs that would be involved. Secondly, because of the nature of risk management data. Although it is possible to quantify some data in risk management, such as accident statistics, the majority of the data that is available is of a richer, more qualitative format that cannot be reduced easily to allow meaningful representation in a 3D map format. Therefore in order to apply information visualisation techniques to risk management a different approach is needed.

Aston University

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Figure 13. Information Visualisation in Three Dimensions (Thomas, 1995)

Aston University

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Figure 14. Information Visualisation in Two Dimensions (Thomas, 1995)

4.9 What is Meant by Risk Visualisation

This is best approached via a metaphor. People without sight, the blind, nevertheless perceive the spatial world around them: not merely the gross position and form of buildings and objects but also the appearance of people, their stature and faces. Without sight, the blind conjure up a mental image of the world through a process that sighted people would describe as visualisation. The argument here is that the process of visualisation applies as well to visual data as to any data, *it is the process and its outcome that are the essential characteristics of visualisation.*

The outstanding example of this process is provided by the life of Helen Keller who, before the age of two had been robbed of her sight and hearing by illness. The following description is quoted from the description of Helen Keller's story provided by the UK Royal National Institute for the Blind (RNIB, 2000):

> *"Anne led Helen to the water-pump and pumped water onto her hand. As she did so she spelt out the individual letters, W A T E R. She did this again and again. Suddenly Helen realised that the individual signs represented the letters that made up the word Water. In the same instant she also realised that everything else in the world must have a name. She rushed about touching anything she could find and asking Anne what it was called".*

An analogous way, where complexity and computational limitations do not permit a graphical depiction of a situation, visualisation will use other means to support a decision-maker to construct a mental model of the decision situation. The question arises as to whether there is a better word than "*visualisation*" to describe this process. Morgan (1993) coined the term *Imaginazation* to describe this process, however, it is a matter of judgement whether this neologism helps. The judgement made here is that visualisation is likely to be better understood and provides a clear indication that graphics are an ideal form for presenting data that are complex either through excessive detail, amount or dynamic internal relations.

The upshot of this for RVS is that whilst ideally supported by graphical communication of data it is not limited to this form alone. What is essential is the notion of supporting creative interpretation and awareness of the risk related aspects of complex decision situations.

4.10 Risk Visualisation DSS Software for Risk Management

"The best way to predict the future is to create it yourself"

"We learn more from our mistakes than from our success"

I like these two quotes that were found several years ago in newspapers. If my memory is correct, the second quote was part of an advertisement for Mercedes concerning a problem with one of their new small class M cars. Even the most famous company can recognise mistakes and take the dynamic of such an unfortunate event in a positive way to modify the mental model of customers about their products.

The quotes illustrate the necessity to review our ideas periodically. The first model for this research was created in 1995 (see Figure 15), and has since been revised many times. This model was used as the basis for discussions with several professors in order to collect useful feedback to improve the RVS concept.

Kleindorfer et al (1993) have proposed the following figure (see Figure 16) to show at a broad level the differences between varying forms of decision-making. They suggest that there is a trade-off between information processing complexity and legitimation/value complexity. When decision-making techniques like intuition and bootstrapping are used, they are typically low on information processing complexity, but high on legitimation/value complexity. This means that they take into consideration the full complexity of the decision problem, weighing up, for example, various ethical, political, business and environmental factors, but that they are only able to analyse a limited amount of information and are only able to manipulate it in limited ways.

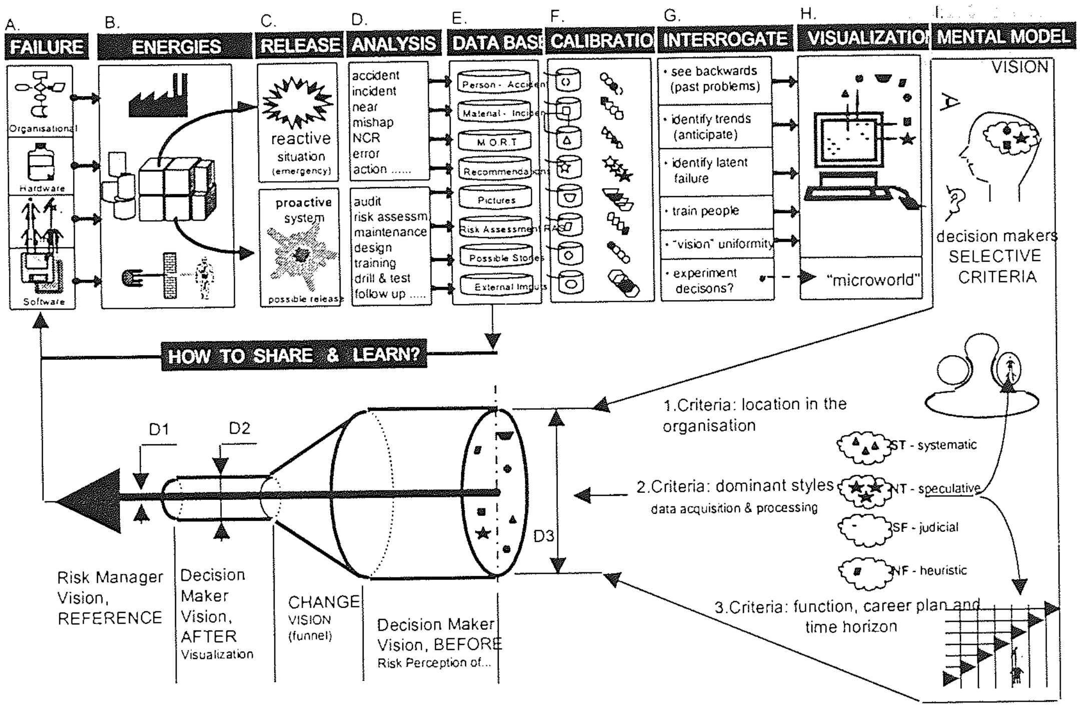

Figure 15. Risk Visualisation Early Model

Figure 16. Information processing in decision-making techniques (Kleindorfer et al, 1993)

Kleindorfer et al (1993) propose that the opposite occurs with decision-making techniques like management science modelling and decision support systems. These techniques allow vast quantities of data to be analysed and manipulated in extensive ways, but the full range of issues surrounding the decision will not be examined, particularly those of a political and social nature.

The RVS DSS software combines the concept of a decision-support system with that of information visualisation. It is intended to support decision-making in a manner that allows the user to analyse large quantities of data and manipulate it in any number of sophisticated ways, whilst still taking into consideration the full complexity of the decision problem. Sauter (1999) in an article about the demise of intuitive decision-making and the need to find ways of promoting it once more in business, has argued that decision-support systems should try to *"blend analytical tools with intuitive heuristics to improve managers' insights about factors too complex to build into models"*. She defines intuition as *"'a sense of feeling of pattern or relationships' and vague feelings"*, and cites definitions of intuition by Thorne (1990) as *"'holistic thinking, immediate insight, seeing the answer without knowing how it is reached'"*, and by Seal (1990) as *"' compressed expertise, a way of rapidly accessing chunks and patterns of knowledge formed from previous experience'"*.

Sauter (1999) has commented that in the past managers would be able to apply intuition in decision-making, which they had gained from years of experience working in their organisation within a particular industry. They would be able to *"reflect more on information provided to them, to imagine creative options, and to seek historical evidence with which to evaluate hypotheses. Their decision-making would generally be more open-ended, involving speculation about unstated possibilities"*. In comparison, the managers of today are unable to apply intuition in this manner because they do not have "*longevity with organizations, products or individuals*". Managers of today frequently change jobs, organisations, geographical location, industries and careers, and as a result are not able to build up the wealth of experience for themselves that can support the use of intuition in decision-making. The days where people could expect to have one job in their life, as exemplified by the Japanese concept in the 1970s, is finished.

Sauter (1999) suggests that one possible solution to this problem is to provide a means for managers to acquire experience vicariously so as to enable intuitive decision-making. This solution could be the development of decision-support systems that combine extensive information processing capabilities in a format that allows the full complexity of a problem to be considered and provides the basis to allow managers to use intuition in their decision-making. Sauter states:

> *"This can happen if DSS provide convenient, quick access to databases and analysis tools so that the decision-makers can "rummage around" to extract and manipulate database fragments in ways that mesh well with individuals' normal ways of viewing and resolving situations".*

With the RVS software the new or inexperienced risk manager will be able to experiment and learn from the rich variety of information and experience recorded in the software by previous people within the organisation. This fits in well with comments Morgan (1997) has made about the factors that distinguish good managers from bad managers:

> *"They have a capacity to remain open and flexible, suspending immediate judgements whenever possible, until a more comprehensive view of the situation emerges. They are aware that new insights often arise as one approaches situations from "new angles" and that a wide and varied reading can create a wide and varied range of action possibilities. Less effective managers and problem solvers, however, seem to interpret everything from a fixed standpoint. As a result, they frequently hit blocks they cannot get around; their actions and behaviours are often rigid and inflexible".*

What the RVS software gives the manager is a way of looking on risk management information from different angles and perspectives, so as to gain experience and promote insight. Shapiro (1997) has described the job of a manager in this way, referring to the difficulties that managers can have when trying to apply conflicting theories in the workplace:

> *"... although conflicting theories are a fact of managerial life, it's the manager's responsibility to make a diagnosis and then, with incomplete information, to act. That's what managers are paid to do: to make tough decisions intelligently in environments of shifting uncertainties".*

Another author who has written about the importance of intuition is Senge (1990). He has commented upon the use of 'intuition' in management:

> *"Intuition in management has recently received increasing attention and acceptance, after many decades of being officially ignored. Now numerous studies show that experienced managers and leaders rely heavily on intuition - that they do not figure out complex problems entirely rationally. They rely on hunches, recognize patterns, and draw intuitive analogies and parallels to other seemingly disparate situations".*

and even Einstein said:

> *'I never discovered anything with my rational mind'*

Risk visualisation provides a new and better way to solve problems in risk management. It is at the cutting-edge of risk management theory and application. It is a new idea, which offers a structured approach to creative thinking, without limiting the risk manager in their decision-making role.

4.11 Summary of Chapter Four

In this chapter the main objective has been to "develop criteria for risk management decision support system (DSS) design". This objective has been also partly addressed in each of the previous chapters, these contributions – such as the application of CSCW criteria and the need to accommodate user and cultural diversity, have been brought forward into this chapter.

Various definitions of decision support systems are available. Most of these stress the coupling of human intellectual skills with the data manipulation and communication abilities of ICT. The majority of definitions emphasise the involvement of the computer in a subordinate role; the tool that supports, rather than the master that directs decision-making.

Another essential feature is the kind of decision situation in which a DSS will be used. Many researchers include the attribute of poorly-structured situations or problems as the setting in which a DSS will apply.

The use of DSS is thought to be of benefit to the quality of the decisions made rather than to the speed at which a decision can be reached. One of the consequences of this is upon the evaluation of DSS effectiveness; measurement of decisions is a highly elusive matter and it is the evaluation of DSS depends upon such measures. However, it is possible to use surrogate measures; in the present research expert evaluation of the software provides some insight into the likely effectiveness of RVS.

Expert systems are distinct from DSS. Expert systems are used to solve problems with algorithms and associated computing strategies. In this respect, expert systems benefit more from classical theories of decision-making than does DSS technology. The other difference is more subtle and reflects the recent movement toward the communication benefits of IT, hence the earlier discussion of the newer term, Information and Communication Technology. Expert systems are typical stand-alone devices even when in networks where the connectivity is to provide supplementary computing capacity.

Expert systems are about delivering answers to problems. In contrast DSS technology help decision-makers to: understand the situations they face and be aware of and test the assumptions that they make. One of the provisos for DSS design is that they should not "*cause undesirable side-effects*": support should not be so strong as to steer decision-makers towards perhaps incorrect conclusions. This is a subtle issue.

DSS technology is new to risk management – in health and safety, software has more pedestrian aims, dealing with the more concrete aspects rather than the ill-structured problems that DSS technology aims to assist. However, it is difficult to have full confidence in the review of DSS applications in the literature as there is evidence that the majority of DSS development is done behind closed doors and not subject to publication.

This research appears to be the first attempt to apply DSS technology in the field of risk management, more specifically, to the health, safety, security and environmental domains. It is also the first attempt to show the advantage of information visualisation to decision support systems.

Decision support systems "contain" a model of the subject domain to which they are applied. This model is not a simulation, simply a framework for arranging and presenting data. The model to be used for RVS is the ESTEC risk management model. To assist the generalisation of this work, the relationship between this and well established models of risk management is made explicit. A difficulty in risk management, and therefore a difficulty for this research also, is the complexity of the issues when considered in their real-world setting. Hence, while simple models can help people get a grip on some issues, ultimately, the complexity of the real world needs to be somehow reconciled with the models. In RVS this is accomplished by mediating inputs to the databases using human judgement.

The huge complexity of the data in risk management presents a great difficulty to encoding information into computers for whatever purpose. Our answer here has been to use another complex system – human input – to recognise patterns and salient attributes from this complexity using keywords and composing photographs in ways that cannot yet be automated. In effect we have addressed a black-box problem (complexity of situation) with a black box solution (sophistication of human perception). Although this apparently leaves the control of the detail inaccessible, black-boxes can be managed by their inputs and outputs. Simply put, input can be subject to appropriate quality control by a risk manager - the black box can be taught and "recalibrated". This is the consequence of the problem of "organised complexity" mentioned in chapter one (page 14).

Ultimately, appropriate computational developed that can handle "organised complexity". When this is accomplished, simulations can then be run in the computer. In the RVS setting, simulations will be those that run "inside the heads" of decision-makers supported by data supplied via the DSS technology.

DSS using information visualisation will, it is suggested, *amplify* human cognition in a way that is analogous to amplication of human strength and speed through mechanical machines.

The question arises as to whether "visualisation" is the best term for the style of DSS investigated here. "Imaginization" is an alternative that could be adopted. However, even when data are not presented visually, the intent is to assist decision-makers create a vision, an understanding, of the aspects of the world that are relevant to their task. The metaphor of blindness is used: the blinds "see" the world in their "mind's eye". The intention for RVS is to support creating a vision of the world in the mind's eye of decision-makers.

CHAPTER 5
RISK VISUALISATION & EXPERIMENTATION

5.1 Introduction

This chapter provides a history of the risk visualisation decision support system that is the focus of this research. The discussion will demonstrate how during the course of the research, ESTEC has advanced from a position where there was no risk management system, to a position where the ESTEC risk management system and Risk Visualisation System have been developed and implemented.

It is important for the reader to understand the general development cycle the RVS DSS. There are three distinct phases to the research concerning the development of the:

- Risk visualisation concept
- RVS prototype
- RVS software

The risk visualisation concept, as outlined in Chapter Four, has been developed from personal experience in risk management. Its design has been informed by a review of management, decision-making, risk management, communication and information technology theories. As emphasised throughout this thesis, the aim is to take a multi-disciplinary approach to tackle the challenge of supporting risk-related decision-making. This chapter explains how the risk visualisation concept has been realised in the form of an RVS prototype. The prototype was created to demonstrate how a risk visualisation decision support system could work in practise. It has been implemented at ESTEC and used on a daily basis to enhance risk management decision-making and communication. The prototype has been subject to an iterative user-centred design process; feedback has been gathered from a variety of sources to guide the continuous refinement of the prototype.

The RVS prototype has been evaluated systematically by applying a software evaluation technique developed by Barker (1998). The evaluation aims to draw out the ways in which the prototype is distinct from conventional proprietary health and safety software. It aims to explore the design of the prototype, identify comparative strengths and weaknessses, highlight issues that require serious consideration, and make practical recommendations for improvement where appropriate. The evaluation is informed by the insights gained when implementing and using the prototype to support risk management decision-making at ESTEC.

This chapter will cover the development and evaluation of the RVS prototype. Section 5.2 will describe in detail the design and construction of the RVS prototype, advancing from the barren landscape of 'ground zero' to the present, far more promising, position. Section 5.3 will present the findings from the detailed evaluation of the prototype. The intention is for the RVS prototype to form the basis for the final RVS software. The prototype is, by its nature, likely to contain imperfections. The lessons that emerge from the software evaluation and the on-going consideration of multi-disciplinary research literature, can be applied to improve upon the prototype. The ultimate questions concern the future of the risk visualisation concept and the RVS DSS. These questions will be addressed in Chapter Six when conclusions will be drawn from the research.

5.2 Design and Construction of the RVS Prototype

This section of the thesis will describe the design and construction of the RVS prototype. The design and construction process is presented chronologically. The description commences by outlining 'ground zero' – the state of risk management at ESTEC when the author was recruited in 1987. This is necessary to 'set the scene' and illustrate the scope and timescale of this research. It then proceeds through the selection of suitable computer hardware and operating systems, the development of the original risk management databases, the creation of the RVS prototype specifications, and the construction of the software by an external software company. For clarity, the timeframe of the various stages of development for the RVS prototype is presented in Table 10.

Year	Design and Construction Progress
1987	• Recruited as Safety Officer by ESTEC
1989	• Selection of IT hardware and operating system • Development of original accidents database
1990	• Development of original risk assessment studies database • Development of original recommendations database
1991	• Development of current version of ESTEC Safety Management System model • Development of original incidents database • Development of original databases for possible stories and external stories
1992	• Development of original picture database
1995	• Development of RVS prototype specifications
1996	• Meeting with ESTEC Computer Division to discuss feasibility of RVS prototype construction
1997	• External software company hired to construct RVS prototype • Completion of software design work • Conversion of photographs into standard format
1998	• Completion and installation of RVS prototype
1999	• RVS prototype evaluation

Table 10: Timeframe for RVS Prototype Development

5.2.1 'Ground Zero'

The RVS prototype represents the culmination of 13 years of practical research into the development of a risk management system and accompanying tools to support risk management decision-making at ESA. In order to understand fully the development process, it is first necessary to consider 'ground zero': the existing 'state of play' when the author was recruited for the position of Safety Officer by the Site Director at ESTEC in April 1987. The Site Director had just returned from the launch pad in Kourou in French Guyana where there had been a fatal accident when an individual fell from the support tower for the Ariane 3 rocket. This had prompted him to recognise the weakness in health and safety management at ESTEC and the need for improvement.

Put simply, at this time ESTEC did not possess a formally defined risk management system. The role of safety officer was viewed as exclusively concerning the identification of technical safety problems and the subsequent proposal of technical solutions. The approach to safety management was predominantly reactive. Indeed, the organisation had not yet advanced to recognising the distinction between the reactive and proactive approaches to safety management (see e.g. Booth, 1993).

The austerity of ground zero is emphasised by the fact that in 1987 there were no safety audits, safety training, safety committees or computer databases for risk management at ESTEC. There was only one paper-based risk management database, which was maintained primarily for legal reasons. It was designed to store only reports for accidents that resulted in injury to people. It was intended to extract information for legal purposes only, and thus was not set up for extracting information for proactive risk management purposes.

5.2.2 Selection of delivery systems

By 1989, as the ESTEC Safety Management System model developed, it became desirable to develop computerised versions of its constituent databases. In order to begin to develop these databases, suitable computer hardware and a reliable operating system were required. The author undertook an investigation to identify the best computer hardware and operating system for the purpose. The crucial criterion was the ability to store and manipulate reliably pictures for the central picture database. The idea behind the picture database was that photographs could be used as a means of visually representing data concerning risk management events such as audits and incidents. This idea has been explored throughout the thesis.

An IBM-compatible PC with an early version of Microsoft Windows and an Apple Macintosh computer were selected for testing. At this point in time, the tests found the IBM-compatible PC to be unsuitable for the development of the picture database. In particular, the user interface was too complex, unreliable and 'unfriendly'.

In sharp contrast, the tests found the Apple Macintosh computer to be highly suitable for the development of the picture database. It was easy to use, featured a 'friendly' user interface and had good reliability. Additionally, the Apple Macintosh computer was capable of supporting work in multiple windows, and could run two monitors simultaneously. This was a huge benefit for the development of the RVS prototype, where the aim is to allow the user to 'surf' through multiple windows of risk management data. The difference between the Apple Macintosh computer and the IBM-compatible PC was substantial in 1989. It was like 'night and day'.

Another determining factor was that in 1989, IBM-compatible PC laptops were extremely poor in comparison to Apple Macintosh laptops. For the risk visualisation concept to be realised fully, it was essential for it to be possible to run the risk management databases on portable laptop computers as well as conventional desktop computers. This would allow the databases to be used in meetings at different sites throughout ESA.

5.2.3 Development of the original risk management databases

As the ESTEC Safety Management System was developed and refined, it became possible to attempt to develop rudimentary independent computer databases to store the abundant risk management data. The databases outlined below were developed and implemented by the author between 1989 and 1992. The databases were independent, with no links between the data that they contained.

In 1989, the first computer database was designed to store data concerning accidents involving injury to people. It was created using Claris Filemaker Pro, a proprietary computer software application for database development. The accidents database was essentially a significantly revised, computerised version of the previous paper-based system. The goal of the revision was to adapt the database for proactive risk management purposes, and remove or simplify all unnecessary datafields that did not help to identify risk management trends or patterns. The development of the accidents database took several months, but the benefits were considerable. So much so that it prompted the development of further risk management databases with the same philosophy – to support proactive risk management, to store only the data that is necessary and to have consistent datafields whenever possible.

In 1990, a risk assessment study database was created, again using Claris Filemaker Pro. The same database application was subsequently used to create a recommendations database to summarise and store the recommendations that are proposed after, amongst others, audits, accidents, incidents, risk assessments or safety committee meetings. The recommendations database was designed to require the user to prioritise recommendations according to three levels of urgency, as this was requested by the Site Director at ESTEC.

By 1991 the recommendations database contained records for over 300 recommendations. It played a crucial role in monitoring safety performance at ESTEC. The number of recommendations that are 'closed' (implemented) is used as a key active monitoring criterion. The recommendations database allowed an annual report to be produced to summarise proposals to improve safety at ESTEC, and to communicate an overall vision of proactive risk management to senior managers.

The early recommendations that were recorded in the database were predominantly reactive and technical. For example, they proposed solutions for inadequate chemical storage or incorrect electrical cable connections. At this time, senior management expected to receive only technical recommendations from a safety officer. They would not accept recommendations concerning management issues. For example, they would not have accepted a proposal to improve inadequate supervision in research laboratories. This was a considerable barrier to improving risk management at ESTEC.

An incidents database was created next using Claris Filemaker Pro. The database was developed in close co-operation with the Flight Safety Product Assurance Department. It arose after the ESTEC Safety Office was asked to produce a revised industrial safety manual and a product assurance manual for testing areas. The request to produce the latter manual involved an extension of the traditional remit of the Safety Office. It necessitated the creation of procedures to record and analyse all types of incidents involving materials.

This was followed by the development of a Claris Filemaker Pro database to record data concerning the details of possible stories and external stories; that is, stories about risk management events that could occur, and those that have occurred elsewhere in the aerospace industry or other industries.

In 1992, a picture database was created using Aldus Fetch, a proprietary computer software application for archiving photographs. The picture database could store and display photographs with associated *keywords* that could be used for searching and a small description. However, storage capacity was a problem because of the relatively small size of computer hard disks in 1991. This meant that in practise only one photograph could be stored for each incident, accident, risk assessment, audit, etc.

In a short time, the quantity of pictures in the picture database increased substantially. Fortunately, computer hardware continued to evolve at a rapid pace, and increases in hard disk capacity meant that it remained feasible to attempt to store a large quantity of pictures in electronic format. However, at this time the technology for recording pictures on computers was not standardised. In order to continue to store pictures year after year it was necessary to use different technologies and picture formats. This resulted in a wealth of pictures stored in a wide variety of formats. The picture database soon became unmanageable due to the difficulties entailed in handling diverse picture formats and organising them in an efficient manner.

5.2.4 Development of the RVS prototype specifications

The specifications for the RVS prototype were developed by the author in 1995 based upon the:

- ESTEC Safety Management System model (see Figure 12)
- Concept of risk visualisation
- Original ESTEC risk management databases.

The fundamental idea behind the RVS prototype was to develop a computer program that could integrate the original ESTEC risk management databases. This would allow links to be made between data and would give the user the ability to 'surf' through the data that is stored in the different databases. Thus, in order to develop the RVS prototype specifications, it was first necessary to examine the structure of the original ESTEC risk management databases to determine how they would need to be modified to make them compatible. This involved:

- Analysing the constituent datafields of each database
- Simplifying the datafields to ensure that the databases record risk management data in a consistent format
- Checking that the data recorded in the databases is relevant for the overall goals of the ESTEC Safety Management System.

Figure 17 shows the refined datafields for the databases in the RVS prototype.

no.	Description of fields	INC	RAS	REC	ACC	**PIC**	STO	EXT	DOC
1	no. reference	x	x	x	x	x	x	x	x
2	year	xx	xx	xx	xx	x	xx	xx	
3	date	x	x	x	xx	x	x	x	
4	time				xx	x			
5	gravity factors	xx		xx	xx	x	xx	xx	
6	location general	xx	xx	xx	xx	x	xx	xx	
7	location specific	x	x	x	x	x	x	x	
8	type of failure	xx	xx	xx	xx	x	xx	xx	
9	hazard involve	xx	xx		xx	x	x	x	
10	agent initiator - vector	o	o		xx	x	x	x	
11	**links with other databases**	**x**	**x**	**x**	**x**	**x**	**x**	**x**	**x**
11	description	x	x	x	x	x	x	x	
12	remark	x	x	x	x	x	x	x	
13	illustration: picture or pictogram	x	x	x	x	x	x	x	x
14	external expert		x			x	x	x	
15	internal expert		x			x	x		
16	cost	o	x	o	o	x	x	x	
17	initiator - origin			xx		x	xx	xx	
18	status (open, close, cancel)	o	x	xx	o	x			
19	action & responsibility for impro.			x		x			
20	injury information				xx	x		x	
21	person information				x	x		x	

xx: pop-up menu entry, x: manual entry, o: to be improved

Figure 17. Refined Database Datafields for RVS Prototype

The specifications for the system architecture of the RVS prototype can best be understood by referring to the ESTEC Safety Management System model, which was shown in Chapter Four. The prototype is designed to contain eight databases to store different types of risk management data. The role of each database is described below.

- **Incidents (INC)**

  The Incidents (INC) database is designed to store data concerning the details of health and safety incidents that result in damaged or lost materials.

- **Risk Assessment Studies (RAS)**

  The Risk Assessment Studies (RAS) database is designed to store data concerning the findings of systematic evaluations of the risks posed by new or existing hazards within the organisation. For example, risk assessments may be conducted for new installations, new testing methods, new technologies, major refurbishment or re-evaluation of residual risk.

- **Recommendations (REC)**

  The Recommendations (REC) database is designed to store data concerning risk management improvements that are proposed based upon the findings of risk assessments, audits, inspections, reviews, meetings, and accident and incident investigations.

- **Accident Involving Humans (ACC)**

  The Accidents Involving Humans (ACC) database is designed to store data concerning details of health and safety accidents involving personnel where first aid has been rendered on site. Records are kept even for accidents that result in only minor injuries to personnel, such as, an employee sustaining bruises as a result of tripping over loose cables in a corridor.

- **Pictures (PIC)**

  The Pictures (PIC) database is designed to store data consisting of 'pictures' that are taken during risk assessments, accident and incident investigations, audits, inspections, reviews and meetings. The 'pictures' are stored in the Pictures database with associated keywords. The 'pictures' can be photographs, video footage, or pictograms.

- **Possible Stories (STO)**

  The Possible Stories (STO) database is designed to store data concerning hypothetical risk management scenarios that may occur that are mentioned in discussions, feedback and meetings. The scenarios are recorded in the database to help to prevent their future occurrence. This is part of the organisational learning process.

- **External Stories (EXT)**

  The External Stories (EXT) database stores data concerning risk management events that have occurred in organisations external to ESA. As with the Possible Stories database, this can be used to enhance the organisational learning process. By learning from external events, a risk manager can prevent similar situations from occurring in their own organisation in the future.

- **Reports and Documents (DOC)**

  The Reports and Documents (DOC) database is designed to store electronic copies of all written documents related to risk management. For example, memos, meeting notes and reports. Each document is given a unique database record number.

The Picture database is the core of the RVS prototype. All of the constituent databases are connected to this core and to each other, creating a network of databases. The Picture database forms the basis of the search engine for the RVS prototype. Whenever a user enters a new picture into the Picture Database, they are required to assign appropriate keywords. The keywords are a means of archiving the pictures. They are descriptive words or phrases that summarise the contents of a picture. There are two main approaches to using keywords to archive data in databases. These are described in the User Manual for Aldus Fetch Version 1.2 (James, 1993):

> *"Library scientists have developed two approaches to keywording - natural language and controlled vocabulary. In natural language keywording, terms are freely assigned to items. In controlled vocabulary, keywording terms are clustered, and preferred terms are assigned to items".*

In the RVS prototype, natural language keywording is implemented following the 'classical approach' of Booch (1994). Keywords are entered for six broad, descriptive categories.

• People	Humans who carry out some function.
• Places	Areas set aside for people or things.
• Things	Physical objects, or groups of objects, that are tangible.
• Organisations	Formally organised collections of people, resources, facilities, and capabilities having a defined mission, whose existence is largely independent of individuals.
• Concepts	Principles or ideas not tangible; used to organise or keep track of business activities and/or communications.
• Events	Things that happen, usually to something else at a given date and time, or as steps in an ordered sequence.

The user of the RVS prototype needs to work through the six categories of keywords when they enter a picture into the Picture database. They thus need to enter keywords for the people connected to the picture, the places connected to the picture, the objects connected to the picture, and so on as outlined above. Because the keywords are entered in natural language, the user is free to choose the exact words that they use to describe the picture. Data is entered into the RVS prototype in the English language, a point that will be explored later in the discussion of the findings from the software evaluation.

The previous chapters in their discussion of communication and intuition have emphasised that it is important not to restrict the way that people understand and describe the world. In the context of the RVS prototype, it is therefore vital that people are not restricted in terms of the range of keywords that they can use to describe a picture that they enter in the Picture Database. The aim of RVS is to let people be intuitive and enter keywords that match their own perceptions of a picture. The only proviso is that the keywords must fit into the broad categories of Booch.

There are both advantages and disadvantages associated with the use of a natural language keyword system. The principle advantage is that natural language keywords will make it easier for people who are not experts in information technology or risk management to use the RVS prototype. The aim is for the prototype to be implemented over the ESA intranet so that it can be accessed by a diverse group of users separated by time and space. This means that individuals throughout ESA will be able to gather and record risk management data, taking photographs and entering their own keywords. In this manner, the number of people who can participate in risk management by acting as 'feeders' who contribute data to the RVS prototype is increased, and greater quantities of data can be collected.

Another second crucial advantage is that allowing users to choose their own keywords lets them to record data according to their own perception of reality (see Chapter Two). It is a means of enabling multiple perceptions to be 'fed' into the RVS prototype. A further advantage is that because there is no restriction on the range of keywords that can be entered into the RVS prototype, it is possible to encourage users to enter as many relevant keywords as they can think of for a given picture. This means that both first and second level data can be encoded, capturing a wealth of contextual data as well as data related directly to risk assessments, audits, inspections and incidents.

For example, if a user was entering data into the RVS prototype concerning an incident where an employee was injured when using a whiteboard with a sharp edge, they would take a photograph of the accident site and gather details of the incident. They would then enter the accident details into the Accident Database, enter the photograph into the Picture Database and enter relevant keywords. The keywords could be **direct keywords** (words that directly concern details relating to the accident), for example, the location, what happened, the date, the type of injury, and the type of whiteboard. They could also be **indirect keywords** (words concerning data that is recorded in the picture which is not specifically connected to the accident), for example, the wall type, the lighting, the floor type, other office equipment that is present and the height of the ceiling. The indirect keywords may prove valuable at a later date when the risk manager wishes to search the RVS prototype for data concerning, for example, the quality of the office floor surfaces within a particular building in a review of fire safety.

The disadvantages of using a natural language keyword system are that as with all natural language, it is possible for individuals to use different words to represent the same meaning, or to use the same word to represent different meanings. Further, there is no limit on the number of keywords that can be used. This can make it more difficult and time-consuming to search the databases for relevant data, as the user may have to enter several different keywords to find the particular data that they require.

The following example illustrates how keywords can be selected for a specific photograph. The example is related to an incident that occurred involving the failure of electrical generator number 2 which is connected to a gas engine. A fire started and the smoke detection system was triggered. The fire brigade was called to the incident site and used halon fire extinguishers to bring the situation under control. The photograph that represents the incident is shown in Figure 18, whilst possible keywords are listed in Table 11. Keywords are listed for each of the six categories identified by Booch. They are sub-divided into those that encode first level data (directly related to the incident) and those that encode second level data (additional information captured by the photograph that is not directly related to the incident).

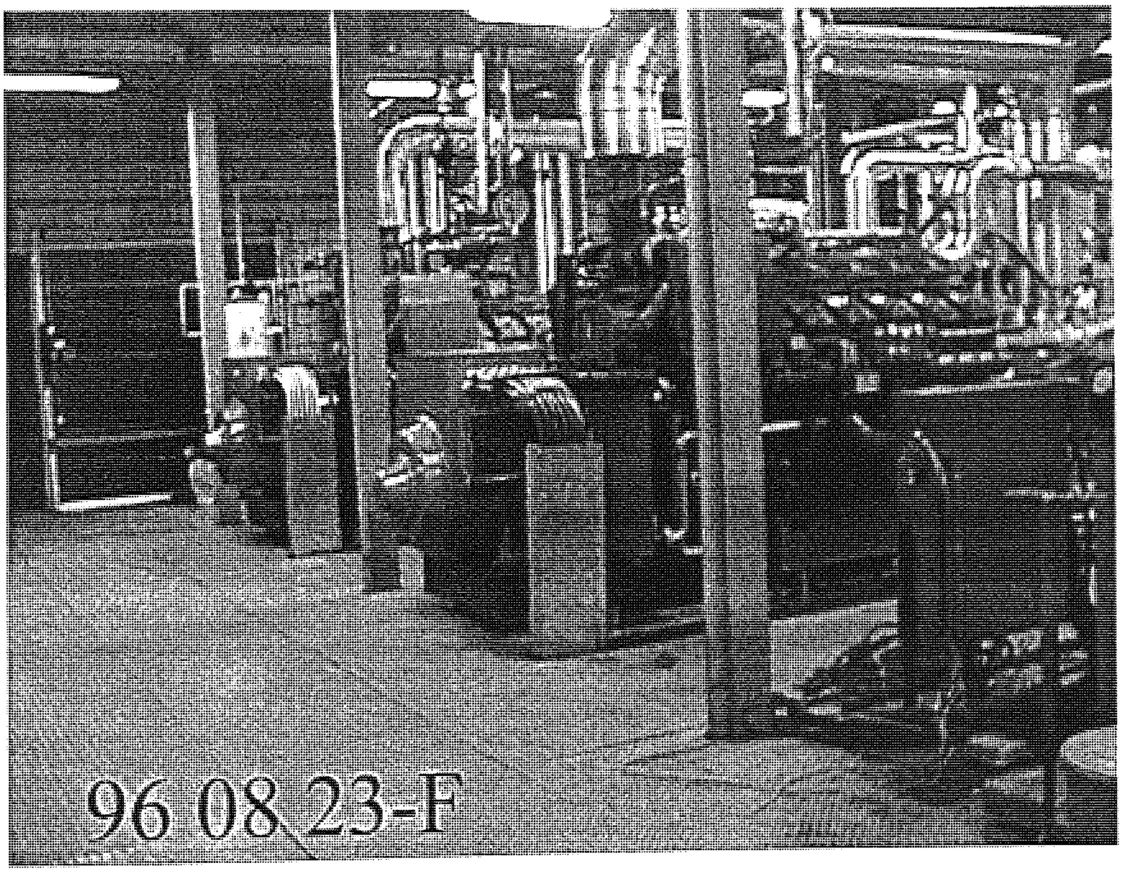

Figure 18: Electrical Generator Incident Photograph

Keyword Category	Possible Keywords for Electrical Generator Incident Photograph	
	1st Level of Encoding	2nd Level of Encoding
People	• Fire brigade • Security (Mr Y) • Technical Shift (Mr X) • Maintenance contractor (Firm Z)	
Places	• Zone Z • LOCZc001 (room number) • Total energy • Boiler house	
Things	• Failure • Power • Energy • Engine • Gas • Fire • Fumes • Smoke • Detector • Power supply • Generator • Cable • Halon • Emergency • Fire extinguisher	• Wall • Concrete floor • Poster • Metal pillar • Building • Doors • Lamp
Organisation	• Testing division • Technical section • MRB (material review board) • REC008.04 • Recommendation	
Concepts	• RAS • INC034-1995 • VTT • FMECA	
Events	• Class B • Incident • INC023-1996 • NCR96-052 • DOC7452 • 1996 • August	

Table 11 : Possible Keywords for Electrical Generator Incident Photograph

Users of the RVS prototype can search the constituent databases by selecting from a list of keywords that is displayed on the main screen or entering keywords in a free text datafield. One or more keywords can be selected to guide the search process. When the user has entered or selected keywords, the databases of the RVS prototype are searched for all data records that list them amongst their related keywords.

The RVS prototype is designed with an open architecture database structure that stresses flexibility, adaptability, and visibility. The version that is described above is based upon the ESTEC Safety Management System, with the databases designed to store the data that is required to support risk-related decision-making within this system. However, the RVS prototype is designed so that an organisation can create and modify the constituent databases themselves, down to setting the exact datafields and screen layout. The only constraint is that certain key datafields must always be included, and that the user-defined databases must be linked together via the Picture database.

Thus, for example, the RVS prototype could be adapted to contain databases to support decision-making within a risk management system based upon BS8800. In this case there could be databases to record data concerning: policy, organisation, risk assessment, reactive monitoring, active monitoring, auditing and review. This flexibility means that the organisation can decide how best to design the databases to match their own risk management decision-making needs, and can decide exactly how the RVS prototype should offer support to decision-makers. They are also free to adapt the databases as necessary to ensure that they continue to meet evolving risk management decision-making needs.

5.2.5 Construction of the RVS Prototype

The RVS prototype was constructed by an external software company based upon the specifications described above. Initially it was hoped that the RVS prototype could be constructed internally by the ESTEC Computer Division. At a meeting between the author and the ESTEC Computer Division in July 1996, it emerged that the idea of risk visualisation was feasible but that it would be difficult to construct the prototype.

In January 1997 the author proceeded to make a formal request to the Computer Division to develop the RVS prototype. A memorandum was produced for the Computer Division to describe the author's vision of the prototype. The memorandum (Schallier, note AOS/7579, 10 January 1997) stated that:

> The idea is to calibrate/weigh files from data following certain criteria, e.g. hazard types, location, risk levels etc ... The picture database is the central navigating tool for research. Action: define methodology tools, resources and software to calibrate each file (mathematical indexation). The next step is to visualise....

In contrast to the earlier "difficult but feasible" feedback, this time the author received a response that the RVS prototype was considered too difficult, even impossible, to construct at ESTEC, and that the necessary software development expertise could only be found externally. This response prompted a search for an external software company who would:

- Possess the necessary software development expertise
- Be able to share the vision of risk visualisation
- Be able to propose a solution to the problem of converting the existing risk management pictures into a consistent format.

In particular, it was a major technological challenge to be able to find a way to create the RVS prototype so that it could store vast quantities of pictures in a well-organised, consistent, logical manner, which would be easy to search to locate a particular picture. The RVS prototype needed to be able to compress, open and export all of the different picture formats that had been used for the original picture database.

The external software company that best met these requirements was the BLS Computer Consultancy based in Maarssen, Netherlands. An initial meeting was arranged between the author and the BLS Computer Consultancy to discuss construction of the RVS prototype. It was agreed that the construction of the RVS prototype should be divided into four distinct phases. A working RVS prototype would be complete by the end of the third phase for a total cost of 25K EURO. The fourth phase was intended to focus upon the development of a web browser to implement the RVS prototype over the ESTEC intranet. The RVS prototype construction phases are outlined in Table 12.

Phase	**Construction Details**
Phase 1	• System design, concept and feasibility. • Design work for a prototype picture-based risk management / analysis tool. • Completion date: July 1997. • Deliverables: 60 page report providing design specifications for the RVS software. The specifications included an RVS Image Database, RVS Data Model, RVS Maintenance Application, RVS Retrieval Application, RVS Scatter Plot and web browser.
Phase 2	• Conversion and importation of data from existing databases. • Development of all RVS databases. • Conversion of 6000 pictures into Visage format. • Completion date: November 1997.

	• Deliverables: Converted pictures.
Phase 3	• Coupling with Claris Filemaker Pro. • Coupling of picture database and existing Filemaker Pro databases. • Development of keyword search engine. • Development of user interface. • Completion date: March 1998. • Deliverables: Installation of first version of RVS. • Completion date: June 1998. • Deliverables: Second and final version of RVS with User Guide.
Phase 4	• Web browser development (see chapter 6). • This phase was unfortunately cancelled due to budget restriction.

Table 12. RVS Prototype Construction Phases

Phase 3 of the RVS prototype construction was completed on schedule in June 1998. This resulted in a working RVS prototype that could be installed on a single computer at ESTEC. Because the RVS prototype has been developed from the original Apple Macintosh risk management databases, it is designed to run on the Apple Macintosh operating system.

5.2.6 Recent advances

At the time of writing, there is far more computer hardware and software available that is capable of storing and manipulating pictures electronically. In recent years, the IBM-compatible PC has gained in terms of its share of the commercial market for picture storage and manipulation, and arguably now has comparable ability to the Apple Macintosh. It is worth noting though that the Apple Macintosh is still dominant in the fields of desktop publishing, graphical design, computer-aided design, photo and video editing, and special effects.

Because the standard computer that is used at ESA is the IBM-compatible PC, it became necessary during the last two years to explore the possibility of developing a compatible version of the RVS prototype. The auxillary computer programs that the RVS prototype relies upon are now available in formats that allow them to run on other operating systems, such as Microsoft Windows. The only exception, albeit a vital one, is Aldus Fetch - the program that is used to store and view the pictures in the Picture database.

So far, all of the data that is stored in the Claris Filemaker Pro databases of the Apple Macintosh version of the RVS prototype has been transferred to IBM-compatible PC format and stored on a server at ESTEC. Because there is not an IBM-compatible PC version of Aldus Fetch, an alternative computer software application has been selected for storing and manipulating pictures. This application is called Portfolio Version 4.1 and it is produced by the Extensis Corporation. It has allowed the data from the Aldus Fetch Picture database in the Apple Macintosh version of the RVS prototype to be transferred to the new IBM-compatible PC version. The extension of the RVS prototype from Apple Macintosh to the IBM-compatible PC should make it easier to use the software to communicate via the ESA intranet and the internet.

5.2.7 Implementation at ESTEC

Following construction the Apple Macintosh version of the RVS prototype was implemented at ESTEC upon the author's desktop computer. Training was organised to explain the concept of risk visualisation to staff at ESTEC, and to instruct them on the purpose and operation of the prototype. From this point, a diverse group of users became involved in gathering and recording risk management data. Regular meetings were arranged to discuss the practical implementation of the RVS prototype with users, and to identify potential problems. This information was fed back into the iterative design process.

To test the idea of using the RVS prototype over the ESA intranet, a networked IBM-compatible, Microsoft Windows version was designed to operate throughout ESTEC. This was implemented in 1999. The networked version features all of the Claris Filemaker Pro databases and the Extensis Portfolio Picture database. The crucial difference between this and the Apple Macintosh RVS prototype is that the automatic links between the databases are no longer included. This is because of a desire to pursue the philosophy of keeping the final RVS software as simple and flexible as possible, with maximum user control. By removing the automatic links, the networked RVS prototype becomes even more adaptable, and any dependence upon the software company that constructed the Apple Macintosh prototype is eliminated.

For the initial test of the networked RVS prototype, six staff in the Industrial Safety and Security team were selected. These individuals were located throughout the ESTEC site. Each was supplied with a high quality computer workstation upon which could access the networked RVS prototype. The staff could enter data into the prototype and search through the databases to inform risk management decision-making. Useful feedback was obtained to further guide the development of the RVS prototype and the final RVS software.

5.2.8 Training

Training is essential if multiple users throughout ESTEC are to participate in using the RVS prototype. There are two categories of RVS user: those who are responsible for entering data into RVS ('feeders') and those who will use RVS to view and manipulate data (See Figure 3 in Chapter Two concerning realities of the world). All users need training if they are to understand fully the risk visualisation concept that lies behind the RVS prototype. It is important for the 'feeders' to recognise that the investment of time that is required to enter risk management data into RVS will be of great benefit in the middle to long term.

To be effective, the RVS prototype needs to store a lot of data, which will take time and effort to collect and record.

The major training challenge is to teach users to use properly keywords when entering data, and to update the keywords when there is progress in an event that has been recorded. For example, if there is a risk assessment, a risk assessment record will need to be entered into the RAS database in RVS and associated photographs will need to be entered into the Pictures database. The user would need to enter keywords to describe the risk assessment and the data encoded in the photographs. Later, there may be a risk management meeting where more elaborate conclusions are drawn from the risk assessment and recommendations are proposed. The user would need to update the risk assessment record in the RAS database and enter an associated recommendations record in the Recommendations database. They would then need to enter additional keywords to describe the contents of the recommendations and the new input to the risk assessment record.

There needs to be a monitoring process to ensure that data is entered correctly for the RVS prototype. At ESTEC this takes the form of a weekly meeting where a few key users gather for an hour to browse through all the pictures in the RVS Picture database. The keywords that are associated with each picture are checked for their relevance and to confirm that they are up-to-date.

The training needs to explain the benefits of the RVS prototype to users and to respond to their initial concerns. For example, users need to be informed to allay any fears that they might have about recording data, including photographic evidence, concerning routine work activities. They need to be briefed on the purpose of RVS, how the software supports risk management decision-making, who will have access to recorded data, how recorded data will be used, and on the political implications of recording data. On the latter point, users need to be assured that the recorded data will be handled ethically, and will not be used for assigning individual blame or bear a negative impact on their career.

Another common concern that new RVS users express is "Why do we need to take pictures all the time?". Individuals are often more concerned about recording visual evidence in the form of photographs than they are about recording textual evidence. Further, the requirement to take photographs necessitates some extra work for those gathering risk management data. They need to have the appropriate digital cameras to hand, be trained in using them, and informed on how to best take photographs of accident and incident scenes, of inspections and risk assessments. It is only through training and participating with the RVS prototype that users can understand fully its benefits and its role in the ESTEC risk management system.

Training is necessary to encourage employees at ESTEC to participate actively in risk management. The aim is to get more people to be "leaders" in risk management rather than "followers". There will be a lot of rotation in the people feeding the system because there will be a large group of "leaders" and in a dynamic environment involving reorganisation/departure/mobility etc this group is never fixed. It is essential to keep them trained, motivated and informed even when they are on another site geographically far away. Training may need to be more complex to accomplish this.

5.3 Evaluation

The RVS prototype has proved invaluable as a means of illustrating the author's vision to others. It has been tested in practise with a few managers at ESTEC, receiving excellent feedback. A positive response has also been received when the RVS prototype has been presented at risk management conferences. Nevertheless for the purposes of this research a more rigorous, systematic and independent means of evaluation was required to provide insights into the comparative strengths and weaknesses of the software.

In Chapter Four it was explained how there is little published research concerning the application of decision support systems to risk management. The vast majority of DSS research is very much conducted behind the 'closed doors' of organisations. It is therefore not possible at the present time to evaluate the RVS prototype by making benchmark comparisons with similar systems. Further, when Silver's framework was presented in the same chapter for describing DSS, it was emphasised that it is extremely difficult to evaluate this type of computer software. How is it possible to assess the influence of a DSS on decision-making in a manner that is both valid and reliable? Given how much remains unknown about human decision-making processes (see Chapter Three), the task of evaluation is daunting.

The solution that was settled upon for this research was to subject the RVS prototype to expert evaluation. The evaluation was undertaken in January 1999 by Dr Amanda Barker of the Health and Safety Unit at Aston University. The evaluation uses an adapted version of a software evaluation technique developed by Barker (1998) specifically for health and safety software. The original technique was created to evaluate proprietary health and safety software. The intention of applying the technique to the RVS prototype was to identify the strengths and weaknesses of the software design, draw contrasts and comparisons between the prototype and conventional proprietary health and safety software, and develop practical recommendations for improvements that can be implemented in the final RVS software.

The technique involves the evaluator systematically progressing through a software evaluation chart that prompts them to consider in detail a wide variety of aspects of the software. The chart is divided into sections of questions on particular topics, such as software installation, the design of menus, feedback, and software compatibility. The software evaluation chart is intended as an exploratory tool to stimulate thought and guide analysis of a piece of software. It can be completed by assigning ratings on a scale of 0-5 for each question that is asked, or by recording qualitative evaluation notes. For this research it was decided that the latter approach was by far the most suitable, because it would 'pull out' the differences between proprietary health and safety software and the RVS prototype. To assign numerical scores seemed inappropriate given the anticipation that the RVS prototype would differ considerably from the proprietary software to which the chart is usually applied.

One of the main questions that is considered is to what extent the RVS prototype differs from the range of proprietary health and safety software that is currently available on the commercial market. It is crucial to tackle this question in order to gain a true appreciation of what is new and distinct about the RVS prototype. The evaluation findings are presented below in the form of a discussion under the headings from the software evaluation chart. It should be stressed that the evaluation will not provide definitive conclusions regarding the RVS prototype, but is instead a starting point from which further evaluative work could be conducted. This issue will be returned to in the conclusions in Chapter Six.

5.3.1 Acquiring the software

The first section of the software evaluation chart concerns issues associated with acquiring the software from external software producers. Whilst this question set is highly relevant for the evaluation of proprietary health and safety software, it is not applicable to the RVS prototype. This reflects the fundamental differences that set the RVS prototype apart from proprietary health and safety software. These differences make the prototype far more flexible and adaptable than its conventional counterparts, giving the user far more control and discretion.

To 'set the scene' some of the fundamental differences will be outlined here, many of which will be examined in greater detail in other sections of the evaluation. Proprietary health and safety software is typically purchased from small software companies. They design the software with the intention for it to be used by a wide variety of organisations in different industries. The small software companies possess varying levels of expertise in software design and risk management. The software is designed in a "one size fits all" manner, with the software company deciding upon the:

- Computer hardware specifications
- Purpose of the software
- Design of the user interface
- Design of the data structures and data fields
- Data to be collected and stored
- Types of data analysis
- Data search methods.

This means that individual organisations have to adapt themselves to match the software rather than the software being designed to match their needs. The organisations have to ensure that:

- Their IT facilities match the set computer hardware specifications for the software
- Their risk management system matches the model of risk management that underlies the software
- They collect, store, search and analyse risk management data within the confines of the software.

Essentially this means that the individual organisation hands over control to the software company, and has to stretch or limit themselves in risk management according to the dictates of the software. The software dictates to the user how they should accomplish particular risk management tasks.

In stark contrast, as has been explained earlier in this chapter, the RVS prototype is custom-made according to the author's detailed specifications. An external software company was hired to construct the software, rather than the software being purchased as a "ready-made and off-the-shelf" product. The RVS prototype is designed to match the information technology resources of ESTEC. It thus matches the hardware specifications of the available computers.

It is based on the ESTEC Safety Management System model (see Figure 12 in Chapter Four) and so matches exactly the organisation's approach to risk management. The software was designed for the purpose of supporting risk management decision-making following the recognition of the need for such a tool. The user interface, data structures and datafields were designed according to the author's specifications. The data can be collected, stored, searched and analysed in the ways that have been identified as most beneficial for ESTEC.

Further, as was explained earlier in this chapter, the RVS prototype has open architecture databases. This means that it is possible for any organisation to use the DSS, creating their own databases which match the specific requirements of their risk management system and deciding upon how the DSS can best be utilised to support risk management decision-making. The RVS prototype gives the user complete control over how they wish to accomplish a risk management task. It is flexible and adaptable rather than rigid.

Finally, unlike many proprietary health and safety computer programs, the RVS prototype can be adapted over time by the organisation to match their evolving risk management needs. Proprietary health and safety software is typically rigidly designed and cannot be adapted to any notable degree by organisations (Barker, 1998). This means that health and safety management tasks have to be performed in the same way each and every time, year-in, year-out. The only way that the software can be adapted is if the software company choose to modify it, and even then this may or may not suit the needs of a given individual organisation. Barker argues that the software takes away the human ability to adapt to their changing environment, and to be creative and ingenious in identifying ways to perform tasks, and solutions to particular problems. In contrast, the RVS prototype is flexible and allows the user to adapt it by designing and re-designing the data structures to match changing risk management needs. The RVS prototype encourages creativity and ingenuity rather than restricting it.

5.3.2 Software installation

This section of the software evaluation chart concerns the ease of software installation. Overall the evaluation found the RVS prototype to be reasonably easy to install. The software installation instructions are included in the user manual and are fairly well written. They use short sentences, bullet points and clear headings. They explain clearly that several auxillary computer programs are required in order for the RVS prototype to work fully (Quicktime, Quicktime Movies, and Claris Filemaker Pro 3.0). They also explain how to link the RVS prototype to the auxillary software during installation.

One of the benefits of the RVS prototype that was drawn out by the evaluation is that the computer specifications that are required to run the RVS prototype match exactly the specifications of the computers used at ESTEC. This is because the prototype was constructed according to the author's detailed specifications. This makes the software installation process significantly easier.

Another considerable benefit is that the RVS prototype is compatible with the ESTEC Safety Management System model and with the existing risk management databases at ESTEC. The latter occurs because the RVS prototype is based upon the author's original risk management databases. It means that it is possible to transfer data from the existing risk management databases into the RVS prototype. This is a great aid to the software installation process. The point will be returned to in the later discussion concerning software compatibility.

However, the evaluation did identify a few drawbacks relating to software installation. Firstly, although the user manual does provide guidance on software installation, it does not provide the specifications for the computer hardware and operating systems upon which the RVS prototype will run. Because of this omission, the present software installation instructions will cause unnecessary confusion and difficulty when new users attempt to install the software.

Secondly, the installation instructions in the software manual do not provide in-depth, step-by-step guidance, instead assuming that the reader has a fair amount of background knowledge concerning computers. For example, the user is instructed to install the RVS prototype from the CD-ROM by copying files to a computer hard-disk or network, but does not give further guidance on this process.

Thirdly, the instructions describe various program files, folders and extensions that will be installed on the computer to set up the database structures, but these are the ones that were specifically created by the author for risk management at ESTEC. If the final RVS software is to be used by other organisations, they will need instructions on how to develop their own databases.

Finally, a practical problem has been identified during attempts to implement the RVS prototype so that it can be utilised by multiple users throughout ESTEC. The problem concerns the need for high quality computer workstations to run the RVS prototype. Each user needs a high specification, multi-media computer workstation with multiple monitors. This is necessary to handle the memory and graphics requirements of the Picture database. The multiple monitors are crucial if the user is to be able to 'surf' through risk management data that is displayed in multiple windows. However, some senior managers think that high quality computer workstations are a luxury not a necessity because of the additional costs that they entail. It can be difficult to persuade them that to commit the required resources. This problem has implications for the future of the risk visualisation concept. The idea that employees throughout an organisation can act as 'feeders' and 'leaders' in risk management could be limited in practise by information technology resources.

It is recommended that the software installation instructions in the user manual should be revised to include detailed specifications for the computer hardware and operating systems upon which the final RVS software will run. Further, they should be examined in detail to identify where further clarity and step-by-step guidance is required. It may be worthwhile testing the installation instructions with naïve users. If the final RVS software is going to be made available to other organisations, the software manual should include detailed guidance on how they can develop and install their own risk management databases.

The question of the costs that will be incurred when implementing the RVS software throughout ESA will need to be addressed in greater detail. As with all risk management tools and solutions, the RVS software needs to be financially viable if it is to be successful in the long-term. The benefits that are accrued from the RVS software need to be greater than the costs that are incurred in implementation and maintenance. The difficulty, as was discussed previously, is how to measure reliably the benefits that the RVS software offers in terms of improved effectiveness of risk management decision-making.

5.3.3 Software manual or instructions

This section of the software evaluation chart concerns the design of the software manual or instructions. As was explained earlier, the RVS prototype has its own software manual that contains the operating instructions. The manual has 13 pages and was developed by the external software company which constructed the RVS prototype.

The user manual for the RVS prototype does not compare very favourably with the user manuals that are typically produced for proprietary health and safety software. In general it lacks detailed, step-by-step guidance and assumes that the user already possesses a high level of knowledge concerning information technology and risk management. The software evaluation identified a number of specific problems related to the design of the RVS prototype user manual. These include that the manual does not:

- Present the full program name on the cover
- Present the program version on the cover
- Include page numbers on the contents page

- Explain how to use the RVS prototype with multiple windows
- Explain how to use the RVS prototype with multiple monitors
- Provide a glossary of technical terms.

One criticism of proprietary health and safety software is that it is rigidly constructed based upon the software designer's understanding of health and safety management rather than that of the user, yet very rarely is the health and safety management basis explained fully in the software manual. In contrast, the RVS prototype is extremely flexible, allowing the user to design the databases according to their own understanding of risk management. Nevertheless, the underlying concepts of a decision support system and of risk visualisation as a tool for risk management still need to be explained sufficiently in the software manual. This is not achieved in the present user manual.

Although health and safety definitions are not provided in the user manual for the RVS prototype, it does not matter since the user designs the data records and defines the key risk management terms themselves. This is a point where the RVS prototype differs from many proprietary health and safety computer programs, since they typically define key risk management terms for the user. The user must then interpret the terms in the same way as the software company rather than according to what is best for their own risk management needs.

Another deficit of the current user manual for the RVS prototype is that it does not explain *how* the user can design their own risk management databases within the RVS prototype. This information is vital if the RVS software is to be used in a flexible manner by a diverse group of users throughout ESA, and also if it is to be used or adapted by other organisations.

Finally, the current user manual for the RVS prototype is in the English language. One question that will need to be considered is whether the manual for the final RVS software should be produced in different languages. This may be necessary if the software is to be used via the intranet across the multi-national sites of ESA, or if it is to be made available for use by other organisations. If the RVS software is intended to overcome language and cultural barriers, and to accommodate diversity, having the manual in only one language would seem an unnecessary hindrance.

It is recommended that the user manual for the final RVS software should be revised and expanded to incorporate greater detail and more step-by-step guidance. The manual needs to contain at least one section to explain broadly the idea of risk visualisation and how the software can be used as a tool for decision-making. It also needs to explain fully how the user can develop their own risk management databases. It may be worthwhile consulting with naïve users to ensure that the instructions contained in the software manual are easy to understand and follow. The revised manual could form the basis for an on-line help system for the RVS software. This point will be returned to later in the section concerning the help system of the prototype. The user manual should be produced in several languages to help to overcome language barriers and reduce the potential for confusion.

5.3.4 Starting the software

This section of the software evaluation chart concerns how easy it is for the user to start the software. During the evaluation it was found that on initial glance it appears to be relatively easy to start the RVS prototype by selecting the appropriate icon on the Apple Macintosh desktop. However, once the icon has been selected, the RVS prototype title screen appears and remains visible on screen until the user clicks on it with the mouse cursor. This is not an intuitive action for the user to take as it ignores software design conventions. Most title screens automatically appear and disappear within a few seconds leaving the user with the main screen of the program. Otherwise they display a macro button labelled "Continue" that the user has to select to proceed. With the RVS prototype, the user may believe that the program has stalled when it does not proceed automatically past the title screen or explicitly prompt the user for confirmation to continue. This is particularly likely to occur with users who are unfamiliar with the RVS prototype, who are weak on informacy skills, or who access the software infrequently. This is problematic given the overall aim of installing the final RVS software over the ESA intranet for use by a diverse group of individuals.

Further, once the user proceeds past the title screen they are presented with a screen that is blank apart from featuring a horizontal menu bar at the top. It is not clear what the user should do at this point; the RVS prototype does not provide any cues or prompts. The experienced user will probably learn what they need to do to proceed at this point, but it is a source of confusion for users who are unfamiliar with the RVS prototype, who are weak on informacy skills, or who access the software infrequently. Again, it is a problem given the goal of installing the software over the ESA intranet for use by a diverse group of employees.

The title screen of the RVS prototype has an attractive, up-to-date design. It makes good use of images, logos, text and colour. It appears that considerable effort has been devoted to its design. The title screen clearly displays the program title, version number, organisation name, software company and software development dates. This allows the user to ensure that they are accessing the correct computer program. The text on the title screen is clearly presented and easy to read.

One good feature of the RVS prototype's title screen is that he does not feature a legal disclaimer. Barker (1998) found that many proprietary health and safety computer programs display a legal disclaimer on their title screen, arguing that they have no legal responsibility for any negative outcomes that may arise from use of the software. This is dubious given that they frequently provide information and data analysis which organisations use to inform risk management decisions. Barker argues that the whole question of legal responsibility of software designers needs to be examined in the context of risk management by those with appropriate expertise. Severe consequences could arise from risk management decisions that are informed by software containing errors or omissions.

From a practical viewpoint the RVS prototype title screen falls short on three points. Firstly, the program title is presented as "RVS Viewer Module". This is clearly different from the title Risk Visualisation System (RVS) that is adopted throughout this thesis. Secondly, the design of the title screen is such that it is extremely difficult to identify the purpose of the RVS prototype. Ideally a title screen should communicate the purpose of the software to the user. The space images that are used on the RVS prototype title screen could feature on any software used at ESA. There is no indication that the software is for risk management in particular. Thirdly, the design of the title screen is similar but different to the design of the cover of the user manual. Crucially, they call the RVS prototype by slightly different names – the "RVS Viewer Module" and the "RVS Viewer". This may make it difficult for the user to be certain that the manual is associated with the software.

It is recommended that the final RVS software should be titled "Risk Visualisation System (RVS)" and that this name should be used in any supportive material. The title screen design should be revised to reflect better the purpose of the software. The title screen and software manual should feature the same design. This should help the user to establish a clear image in memory that they can use to recognise the software and its associated manual. When the RVS software is started, the title screen should be presented briefly then disappear automatically or display a continue button for the user to select to proceed. The software should then present the user with a screen asking them which database they wish to open.

5.3.5 Main screen

This section of the software evaluation chart considers the design of the main screen of the software. The evaluation found that the main screen of the RVS prototype has an intuitive design. It is relatively easy for the user to see how to use the main screen to access the various software functions. The main screen has a neat, attractive layout. It provides the user with a menu-based navigation system, but no toolbars or icons (this point is discussed further below). The main screen provides macro buttons with text labels that the user can select to access each of the constituent databases within the RVS prototype.

The main screen of the RVS prototype contains the keyword search facility. This allows the user to search through the different databases for data records that make reference to specific keywords. The keyword search facility is highly flexible. The user can select one or more keywords from an alphabetically ordered list that contains every keyword that has been entered into the software. They can also enter one or more keywords in free text. Once the keywords are selected, the user can choose to search for data records that match at least one of the keywords or those that match all of the keywords. They can also limit the search to data records from particular years or months. The search results are displayed in a table listing each matching data record. The user can select any of the listed data records with the mouse cursor and they are opened automatically in new windows for viewing.

Because the RVS prototype is designed so that its constituent databases are linked together via pictures and keywords it is much easier for the user to search for particular data. For example, the user can search the RVS prototype for the details of a particular event, such as an incident or audit. They can locate the related data records even if they can only partially recall the details of the event from long-term memory. To illustrate, if the user knows that a recommendation was proposed concerning the use of lasers in a specific laboratory sometime during the last five years, but cannot remember its details or the context in which it was made, they can search for the related data record via two methods:

1. They could access the Recommendations database directly to search for the particular recommendation via traditional database search methods.

2. They could search by entering keywords such as "lasers" or "laboratory" or "[year]" on the main screen to search all of the databases simultaneously for data relating to the keywords. This would find not only the data record featuring the required recommendation but data records concerning the surrounding context, such as records relating to risk assessments and incidents with lasers, relevant legislation, training records, and protective equipment for use with lasers.

The latter search method is available because of the connectivity of the RVS prototype and means that it is possible to search the databases for any data on a particular topic, even if that topic is only vaguely defined. For example, the user could search the databases for any data about "floor surface" or "radiation" or "electricity" or "procedures" or "fire protection systems". This is a similar philosophy to that of internet search engines, even though the technology is different. It provides the user with great flexibility and control.

The evaluation identified a few difficulties regarding the design of the main screen. Firstly, the main screen does not feature a status bar at the bottom to describe the available options as the mouse cursor moves over them. This feature is widely provided in proprietary computer software, including many health and safety programs. Its absence means that the user needs to memorise the meaning of each menu option label. This point will be returned to later in the section concerning feedback.

Secondly, whilst the keyword search facility offers great benefits to the user of the RVS prototype, in practise it has not proved easy to implement in its present format. When the RVS prototype was implemented at ESTEC with multiple users who were trained to collect and enter data into the databases, it was found that the users had no problem taking the necessary photographs and notes and recording them in the appropriate databases. However, they did have considerable difficulty in allocating appropriate keywords according to Booch's system (as outlined earlier in this chapter). When users found this task difficult, they tended to enter less data into the databases, essentially avoiding the task as much as possible. From discussions between the author and RVS prototype users at ESTEC, it emerged anecdotally that they were uncertain of how to use the keyword system and afraid of missing out important keywords, entering too many keywords, or using the wrong keywords.

It was found that when the users were reporting directly to the author, it was possible to encourage them to enter data into the RVS prototype because of the authority that comes with the role of Head of Safety and Security. The challenge arises when trying to implement the RVS prototype with multiple users based across ESTEC, many of whom may be outside the risk manager's direct chain of command. How can employees throughout an organisation be encouraged and motivated to participate in gathering, recording, sharing and learning from risk management data? For many employees, the request to participate with this type of interactive risk management project may seem to place an additional burden upon them beyond their normal work duties.

Another issue related to the use of the current keyword system is that, in many ways the keywords have proved to be a barrier in a multi-cultural environment. The difficulty which individuals have in understanding and applying Booch's keyword system was under-estimated at the start of this research. As was mentioned earlier in the chapter, numerous benefits are accrued by allowing users to enter keywords in natural language. But whilst natural language brings with it flexibility, user control, and a way of encoding multiple perspectives, it also leads to users entering many different words as keywords to convey the same meaning. Further, because the RVS prototype does not incorporate spell-check, dictionary or language translator functions, it is possible for users to enter keywords that are spelt incorrectly, or which come from different languages. This has implications for data integrity. With risk management software any errors in data could lead to confusions that could have serious implications if the data is used to support decision-making. This issue is explored by Barker (1998).

Table 13 provides examples from the RVS Prototype that illustrate how a number of similar keywords can be entered by users, some of which are spelt incorrectly, some of which are in different languages and some of which are grammatical variations.

Keyword Topic	**Variety of Keywords Entered**
Smoke	• "Smok" x 3 (*spelling error*) • "Smoke" x 55 • "Smoke test" x 70 • "Smoker" x 2 • "Smoking" x 1
Solvent	• "Solvent" x 2 (*English*) • "Solvant" x 3 (*French*)
Spacecraft	• "Spacecraft" x 242 • "Spacecrft" x 1 (*spelling error*) • "Spcecraft" x 1 (*spelling error*)
Stairs	• "Stair" x 61 • "Staircase" x 19 • "Stairs" x 3
Standby	• "Stand by" x 2 • "Stand-by" x 4
Test Centre	• "Test centre" x 359 (*English*) • "Test center" x 819 (*American English*) • "Test cneter" x 7 (*spelling error*)
Test Area	• "Test area" x 8 • "Testing aeas" x 1 (*spelling error*) • "Testing are" x 24 (*spelling error*) • "Testing area" x 330 • "Testing area test centre" x 7 • "Testing areas" x 718

Table 13. Examples of Similar Keywords Entered by Users of RVS Prototype

Table 14 emphasises further the difficulties that can arise with the use of natural language keywords. It illustrates the range of keywords that have been entered at least 100 times in the RVS prototype. The reader should note that many of the keywords listed are technical terms or abbreviations used at ESTEC. The table raises some intriguing questions, such as what is the semantic difference between the keywords:

- "Office" and "Room"?
- "Survey", "Inspection" and "Visit"?

The latter question is particularly important from a risk management viewpoint.

One question that the preceding analysis raises is whether or not the RVS prototype should be designed to operate in more than one language. At present data is recorded in the English language only. Thus although the RVS prototype emphasises the visual representation of data to overcome language and cultural barriers, user participation is restricted by the need to possess a high level understanding of English.

As a final point, the keyword window that displays the alphabetical list of all keywords that are entered into the RVS prototype is less easy to use than it could be. Although there is a scroll bar for the user to scroll through the list, within a short period of time the list is likely to be extremely long. The RVS prototype does not include a function to allow the user to 'jump' through the keyword list to locate the ones they require. For example, many proprietary health and safety programs would provide the user with a datafield in which they could type the starting letter(s) of the keyword that they are looking for and be taken automatically to any matching keywords.

Keyword	No.	Keyword	No.	Keyword	No.
Access	159	Corridor	193	Hydra	255
Accident	146	Cptr	145	Incident	1251
Airport	110	Crane	336	Inspection	976
Asbestos	203	Csg	244	Insurance	187
Asphyxiate	109	Door	332	Iso	101
Audit	666	Electrical	443	Kitchen	197
Barrack	133	Emergency	113	Kourou	244
Basement	198	Epr	146	Laboratory	574
Bottle	111	Equipment	180	Ladder	124
Bowring	120	Ers	162	Lamp	370
Building	135	Escape	181	Leak	408
Cable	182	Explosion	206	Lifting	177
Campaign	114	External	180	Lss	433
Ceiling	162	Façade	319	Mission	199
Chemical	248	Failure	170	Ncr	547
Class b	652	Fall	178	Nitrogen	222
Class c	621	Fire	884	Office	212
Clean room	286	Fire brigade	154	Outside	117
Committee	505	Flammable	186	Panel	263
Computer	162	Floor	273	Parking	116
Consultant	109	Fume	110	Photo	297
Contamination	212	Gas	176	Pipe	254
Contractor	214	Guyane	177	Ppf	136
Procedure	234	Tank	178	Transport bay	126
qpc	268	Test	209	V55	177
Recommendation	761	Test area	107	V56	177
Refurbishment	271	Test center	819	Visit	758
Remove	127	Test centre	359	Wall	191
Report	102	Testing	805	Water	470
Risk	946	Testing area	330	Window	199
Road	160	Testing areas	718	Wood	141
Room	111	Tidiness	175	Ycv	108
Roof	296	Training	242	Yto	1158
Survey	244	Transport	212	Zone f	235

Table 14. Breakdown of Keywords in RVS Prototype (n>100)

There are several recommendations that can be drawn from this part of the evaluation. Firstly, it is recommended that a status bar is incorporated into the final RVS software to enhance user feedback and reduce memory burden. Secondly, it would be useful to have a datafield on the keyword window whereby if the user wishes to locate a particular keyword such as "asphyxiation", they can enter "a" or "as" or "asph" and be presented with a shortlist of the keywords that start with these letters. This would locate not only the keyword "asphyxiation" but also variants like "asphyxiate" and "asphyxiated".

It is recommended that a simpler approach is taken to allocating keywords. Booch's system is fine from a theoretical viewpoint, and may work in practise with highly trained, well-educated, highly motivated employees. However, it is too complex and time-consuming for use by the average employee. Alternative approaches need to be identified and field tests conducted to evaluate their effectiveness. The author has already addressed this issue to some extent by issuing guidance on a simpler approach to entering keywords. This approach will need to be evaluated. Training, written instructions, and on-going support will need to be examined in greater detail to ensure that the keyword system is understood fully by users.

Further, there is clearly a need to develop keyword quality control guidelines. One possibility that the author has considered is for the final RVS software to be designed to allow the risk manager to examine all of the keywords that have been entered and to manipulate them to ensure consistency. For purposes of analysis and monitoring, the risk manager could create a set of master keywords, and periodically assign the keywords entered by employees to the most appropriate master keywords. This approach would combine the flexibility of natural language keywords input with a more consistent, standardised means of analysing the raw keywords. It would make it possible for the risk manager to check how many keywords have been entered during the last month in each master keyword class, and the rate of increase compared to previous months. This could serve as an active monitoring indicator. The danger with this is that to some extent the risk manager will be re-interpreting the data entered by employees. However, since the raw keywords will be retained, this is no different to any research technique where raw data is codified for analysis.

Clearly the idea would need to be thoroughly tested to determine its feasibility, reliability, validity and effectiveness.

Another recommendation is that the final RVS software should have a dictionary facility that operates when users enter keywords. This would help to prevent spelling errors from occurring in the first place. It might be possible to have a language translator built-in to the RVS software to help the user to identify the most appropriate English terms to use as keywords. The language translator would need to be able to translate between several languages and explain the meaning of words.

With a diverse group of multi-national users, it may be that the most ideal scenario would be one where users could record and view data in any language. One advanced possibility is an automatic language translator. It would need to be highly accurate to avoid errors in translation, as they could have serious implications in a risk management context. The question of whether the RVS software should be restricted to one language will be addressed further in Chapter Six when conclusions are drawn from the research.

5.3.6 Menus

This section of the software evaluation chart considers the design of the menus of the software. One strong feature of the RVS prototype is that the menus are designed according to the Microsoft Windows/Apple Macintosh standard. This means that the operation of the menus in the RVS prototype will be familiar to any users with some experience of contemporary computer software. The menus are simple, logically ordered, and have clearly labelled options. Short-cut keys are available for the menu options, and when particular options are unavailable they are dulled out. The menus in the RVS prototype compare favourably with those typically found in proprietary health and safety software.

One problem that was identified concerns the options that are available for the user to navigate through the data records in a particular database. Although there are options available for the user to go to the "previous record" and the "next record", these only allow the user to move backwards and forwards through the sequence of records that they have *viewed* from the database. The RVS prototype does not feature menu options to allow the user to move to the previous or next record *in the database*. This is inconvenient and time-consuming.

A second problem is that one of the menus is labelled "RVS" which is confusing, since the user is already within the RVS prototype. A third problem lies with the "Windows" menu, which provides similar functions to the conventional "Windows" menu in proprietary software that is designed for Microsoft Windows/Apple Macintosh. It lists the different windows that the user has open, and provides an easy way for the user to switch between them. This option should be available to the user on every data screen, but is only available when the user opens a movie record.

A final point is that the menus for the RVS prototype are presented only in the English language. This may act as a barrier and source of confusion for users of different languages and cultures.

It is recommended that a "Windows" menu should be provided for every data screen in the final RVS software, and a menu option should be provided to allow the user to navigate backwards and forwards through the records in a database. The menu that is labelled "RVS" should be re-named to avoid confusion. Since the RVS prototype is intended to cross language and cultural boundaries, it may be most effective if it were designed to operate in different languages.

5.3.7 Toolbars

This section of the software evaluation chart concerns the design of toolbars in the software. The evaluation found that the RVS prototype does not feature toolbars. Toolbars are frequently an integral component of the user interface in proprietary computer software. They are present in some, but not all, proprietary health and safety software. The absence of toolbars from the RVS prototype needs to be justified. The user is dependent solely upon an English language menu-based navigation system. This seems incongruous given the overall focus upon visual representation as a means of overcoming cultural and language barriers, and the intention for the software to be utilised by a diverse group of multi-national users.

In comparison, only a few proprietary health and safety programs feature toolbars, although many feature icons in the form of macro buttons for commands. The lack of toolbars can be viewed as a deficit of proprietary health and safety software since it is inconsistent with the user interface design of the majority of software for the Microsoft Windows or Apple Macintosh operating systems.

It is recommended that toolbars and icons should be incorporated in the final RVS software as a means of visually representing commands. Research would need to be conducted to identify the most appropriate icons to use to overcome cultural and language barriers.

5.3.8 Data structures

This section of the software evaluation chart concerns the design of the data structures in the software. The RVS prototype differs considerably from proprietary health and safety software in terms of data structures. The strong points of the RVS prototype are its flexibility, adaptability, user control and user-centred design. Because the RVS prototype was custom-made to the author's specifications, it is capable of recording exactly the data that is required for the ESTEC Safety Management System. Further, it is able to record this data in the exact format that ESTEC desire.

The flexible nature of the program means that the user can design and modify the data structures as required to fit different data, as long as certain key datafields are featured. The user is given the freedom to decide exactly how to use RVS to support decision-making, and is provided with tools to design their own risk management databases. The high level of user control includes being able to choose, amongst others:

- Headings
- Datafields
- Control buttons
- Items on drop-down lists
- Screen colours
- Screen layout
- Text size
- Text font
- Language.

With Claris Filemaker Pro as an auxillary computer software application for the RVS prototype, it is relatively easy for the user to design their own databases with attractive, well-organised data screens. In order to achieve this, the user needs an understanding of databases and familiarity with Claris Filemaker Pro. Compared to other database design applications such as Microsoft Access, Claris Filemaker Pro is reasonably intuitive and easy to learn.

In stark contrast, with proprietary health and safety software, the user is constrained to recording the data which the software has been pre-set to gather, in a pre-set order, with a pre-set level of detail, in a pre-set format (Barker, 1998). The user normally cannot alter the type of data that is recorded, the order in which data is recorded, the detail in which data is recorded, or the format in which data is recorded.

Proprietary health and safety management software is designed typically with rigid, set data fields, screen layout, screen colours, text size and font, and even in many cases set answer lists from which to select (Barker, 1998). Barker argues that when they do provide the user with modification options, these are usually extremely few and limited. At the most, the user may be allowed to add one or two user-defined data fields, or to record extra data in a notes data field, though even these facilities are often lacking.

The RVS prototype provides the user with the ability to work in multiple windows. This allows them to 'surf' through data, viewing, for example, an incident report in one window, a picture from the incident site in a second window, recommendations from an audit in a third window, and a risk assessment study in a fourth window. If the user possesses computer hardware that allows them to connect multiple monitors, they can view an array of data in different windows that are displayed across the monitors. With the RVS prototype the only restriction on the number of windows that can be open simultaneously is the computer's memory resources. Figure 19 shows a typical screen from the RVS prototype where a user is surfing through data in multiple windows.

The ability to surf through data that is presented in multiple windows gives the user several advantages:

- It improves the speed at which the user can work
- It removes the frustration of having to constantly open and close windows manually
- It reduces the short-term memory load of trying to remember information whilst closing one window and opening another.
- It allows the user to view a variety of data in one go.

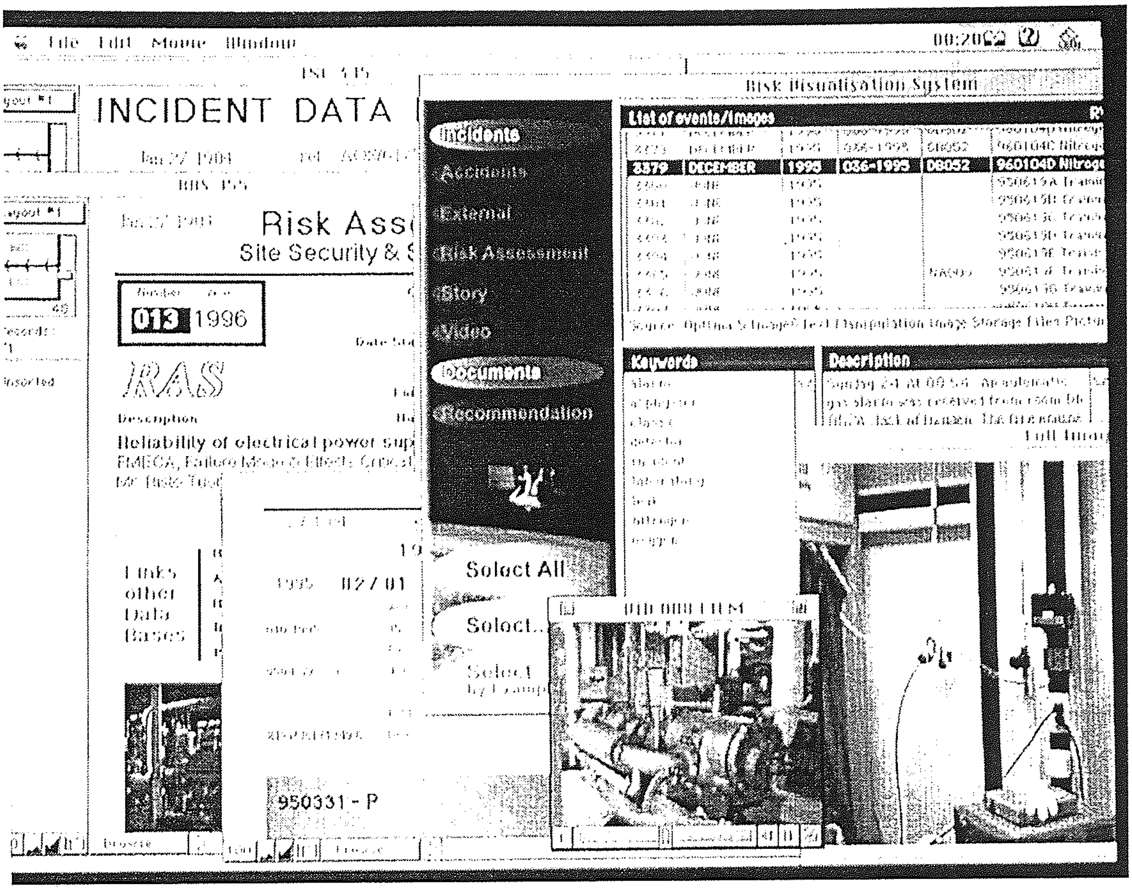

Figure 19: Surfing Through Data in Multiple Windows

This is in sharp contrast to proprietary health and safety software that typically allows the user to work only in one window at a time, inconveniently having to close the current window before being allowed to open another (Barker, 1998). Barker argues that this is restrictive, preventing the user from making easy comparisons between data that has been entered in different data structures, and from switching backwards and forwards between two or more tasks.

The only question mark regarding the data structures in the RVS prototype is how much guidance the software manual and help system should provide for the user in terms of how to design their own risk management databases, and how to get the most out of the prototype. This point was examined in the earlier section concerning the design of the software manual.

As a final point, as was mentioned in the section concerning the evaluation of the main screen of the RVS prototype, it needs to be considered whether it should be possible to record and display data in different languages.

For recommendations, an on-line tutorial could be provided in the final RVS software to outline the nature of a decision support system and the concept of risk visualisation to the user. The tutorial could guide the user through the process of designing their own risk management databases. It could be available in several different languages. It may also be beneficial for the RVS software to feature a range of risk management database templates that the user could adopt or adapt as appropriate. This would hopefully facilitate the learning process and encourage creativity.

5.3.9 Data manipulation

This section of the software evaluation chart concerns the data manipulation capabilities of the software. Proprietary health and safety software typically features basic statistical analysis capabilities. Data entry is normally standardised and codified to allow statistics to be generated. It is then usually possible to present the results of the statistical analysis in the form of graphs and charts. Whilst data standardisation and codification clearly bring some benefits, they also greatly restrict the range of data that can be recorded and its format. Proprietary health and safety software tends to neglect the richness and variety of the information that surrounds the risk manager in their work environment. Further, it tends to dictate to the user how data can be manipulated and for what overall purpose.

In contrast, the RVS prototype does not standardise and codify data. This does not however mean that data cannot be extracted from it for statistical analysis. The design of the databases is left to the user's discretion, as is the means of analysis. Thus the databases could in theory be designed to record data in a standardised, codified format that allows statistical analysis to be undertaken by exporting data into proprietary statistical software. Thus, with an incidents database, statistical data could be generated concerning the:

- Total number of incidents that have been reported
- Number of incidents that have occurred each year over the last 10 years
- Number of incidents that have occurred in different locations throughout the organisation during each month of a year
- Number of incidents have resulted in different types of damage

Similarly, with other risk management databases like those used at ESTEC, it would be possible to monitor, amongst others, the number of:

- Risk assessments undertaken during each month of a year
- Recommendations proposed during each month of a year
- Recommendations closed during each month of a year
- Data records concerning a particular issue, such as hazardous substances or electricity or lasers or procedures or asbestos or spacecraft.

In many ways this makes the RVS prototype a far more flexible tool than proprietary health and safety software as statistics can be generated and trends monitored for a wide range of reactive and proactive performance indicators. The constituent databases can be interrogated from many different angles for different purposes. At ESTEC, the RVS prototype has been used to create annual risk management reports for senior managers, to provide data for training material and presentations, and for research into particular issues using the search techniques evaluated earlier in the section concerning the design of the main screen.

One of the best ways to consider the data manipulation capabilities of the RVS prototype is to examine some of the ways in which it has been used in practise by the author to support risk management decision-making since its installation. In Chapter Four when models were discussed, one significant advantage was the ability to manipulate a model so as to test in a safe environment the implications of different decisions. In the context of risk management, decision-making often occurs in connection to identifying hazards, assessing the tolerability of the risk that they present, and selecting amongst alternative control measures. The RVS prototype provides a tool to enable a risk decision-maker to perform these tasks more effectively. There are a variety of ways in which the RVS prototype can be used to manipulate and experiment with data. This includes the modification of photographs and video footage in real-time for the purposes described below:

- **To clarify information.** Sometimes it can be difficult to communicate clearly about a risk management issue. This can often be the case at ESTEC because of the technical jargon in risk management and the range of languages and cultures. It can necessitate the devotion of time and effort to explain the background to a particular situation, such as an incident that has occurred, or the findings of an inspection. There can be confusions over minor details that have to be clarified and agreed before the discussion can progress to the most important points. The pictures and video footage that can be stored in the RVS prototype can be used to resolve potential confusions, overcoming language and cultural barriers.

- **To illustrate hazards more clearly**. This can be accomplished by exporting a photograph from the Pictures database in the RVS prototype to proprietary photo-editing software. It is then possible to circle in real-time the hazards in a particular location shown in a photograph. This task could be performed during a meeting to illustrate particular hazards that are under discussion, or during a training exercise where employees may be asked to identify the hazards in the photograph. When there are multiple photographs of a hazard or incident, it is possible to add circles, arrows, motion lines and comments in real-time on top of the photographs to illustrate particular points. This works especially well if the user has a large monitor, multiple monitors or a multimedia projector.

- **To demonstrate the sequence of events in an incident.** The user can display a number of photographs related to a particular incident from the Pictures database to illustrate the sequence of events. The photographs could be displayed in multiple windows on multiple monitors or onto a large screen via a multimedia projector. The organisation may have several photographs in the Pictures database of the incident site at various points in time before and after the incident. On occasion, there photographs may be available that were taken during an incident. By exporting the photographs into proprietary photo-editing software, the user can add circles, lines and comments to them to demonstrate visibly how the incident occurred. For example, when part of the façade fell down from the top of an ESTEC building in galeforce winds, it was possible to illustrate what had happened by displaying a photograph of the façade before the incident, a photograph of the façade after the incident and a photograph of the piece of fallen façade lying on the ground. In photo-editing software, lines were drawn onto the photographs to indicate the motion of the piece of façade when it fell.

- **To modify a photograph to emphasise the risk that a hazard represents.** For example, a photograph in the Picture database of a corridor blocked with obstacles such as rubbish and equipment can be exported into proprietary photo-editing software. It can then be edited to draw on top of it the image of smoke coming from around the corner, visibly illustrating the point that the blocked corridor could represent a significant problem in the event of a fire.

- **To demonstrate possible solutions to a particular risk management problem.** For example, at ESTEC a problem was identified involving the position of gates on a road used regularly by vehicles. The vision of drivers was obscured by the position of the gates and the road layout. In this case, it was possible to use photographs from the Picture database to illustrate the hazard, as described previously. It was also possible to export photographs into proprietary photo-editing software to draw possible modifications to the gates. Before and after photographs could then be presented to senior management to emphasise the current problem and what was needed to resolve it.

- **To demonstrate progress**. The pictures that are stored in the Picture database of the RVS prototype can be used to demonstrate progress on particular risk management issues. Pictures can be exported into proprietary photo-editing software for manipulation as described previously to emphasise how progress has been made from point A to point B. For example, visits from the fire building insurance company have taken a new dimension since the RVS prototype has been used. In the past, it was necessary to have a long introductory meeting before the visit took place. This involved extensive report reading and lengthy discussions between the two parties to clarify any uncertainties about the improvements that they had been proposed previously and what ESTEC had done since then to implement the recommendations.

With the RVS prototype, ESTEC can give structured, visible feedback to the fire building insurance company. For instance, in 1996, they recommended that ESTEC install a fire detector behind a mobile platform in the testing areas. During a meeting in 1997, ESTEC were able to demonstrate progress in this matter by showing them photographs from the RVS prototype. This made it much quicker and easier to communicate accurately the progress that had been made in implementing the recommendations.

The RVS prototype makes it possible for an organisation to demonstrate explicitly the nature of the 'starting position' and its associated challenges, the recommendations that have been considered, the recommendations that have been implemented, what is in progress and what still needs to be done. They can visibly show the extent of their commitment to risk management to external or internal parties. This type of feedback is crucial in risk management, where organisations need to demonstrate that risks are being managed with skill and efficiency.

- **To identifying new risks or changes in existing risks.** A key feature of the RVS prototype is its ability to assist risk decision-makers in their search for latent failures or bifurcations. The data that is stored in the constituent databases can be explored in multiple windows, analysed and manipulated to identify trends and recognise new or increased risks. The RVS prototype is able to surpass proprietary health and safety software in this respect, because it encodes a far greater quantity of data in a richer format that reflects the perceptions of employees throughout the organisation.

5.3.10 Saving data

This section of the software evaluation chart concerns the design of the save functions in the software. The evaluation found that all save functions are automatic in the RVS prototype. Whenever the user enters, modifies or deletes data, the changes are automatically saved. This is convenient since it means that data cannot be lost if the user forgets to save changes. The RVS prototype differs from proprietary health and safety software where users typically have to select a 'save' option or complete work on an entire data record before changes are saved automatically.

However, the usefulness of the automatic save function is somewhat offset by the absence of an 'undo' function. This means that once the user has changed the data in a particular datafield and has then selected another part of the data screen with the mouse cursor, the changes are automatically saved and cannot be reversed. This is likely to be a considerable problem, since the majority of proprietary software features an 'undo' option, users are likely to assume that the option is available in the RVS prototype. The problem will be magnified if the software is to be used by a diverse group of users who may possess varying levels of informacy and risk management skills.

It is recommended that an 'undo' function is incorporated in the final RVS software.

5.3.11 Backing-up data

This section of the software evaluation chart concerns the design of the facilities that the software provides for backing-up data. The evaluation found that the RVS prototype does not provide a facility to enable the user to back-up the data records in the different risk management database. Further, the user manual does not explain that data needs to be backed-up regularly as a safeguard against corruption, human error, theft, fire or other damage. The user manual does not describe how the user can back-up data from the RVS prototype, nor how they can reload data that they have backed-up previously. In other words, the RVS prototype assumes that the user will already possess the necessary knowledge and expertise to undertake this task.

In this regard the RVS prototype is similar to the majority of proprietary health and safety software. Proprietary health and safety software of the late 1980s and early 1990s tended to feature a data back-up facility as standard. However, the equivalent software from the mid-1990s onwards often fails to include such a facility, or to explain how to back-up and restore data in the on-line help system and user manuals. This is in effect a step backwards.

It is recommended that the software manual and on-line help system should explain why it is essential to back-up regularly data and suggest a suitable back-up schedule. A data back-up facility should be built into the final RVS software. The software manual and on-line help system should provide detailed step-by-step guidance on how to use the in-built back-up facility. If a back-up facility cannot be incorporated, the user manual and on-line help system should provide step-by-step guidance on alternative ways to back-up data from the software. A prompt should be incorporated into the RVS software to remind periodically the user of the need to back-up data.

5.3.12 Feedback

This section of the software evaluation chart concerns the design of the feedback that the user is presented with when they interact with software. The RVS prototype provides reasonable feedback to the user that compares favourably to that typically provided by proprietary health and safety software. It provides clear feedback to the user when a command is processed, and when the user enters data incorrectly or selects the wrong command.

There are a few points within the RVS prototype where the feedback needs to be improved. In particular, when the user selects an important command that is irreversible. Also, as was mentioned previously, the prototype does not feature a status bar to inform the user of the options that the mouse cursor moves across. A status bar is normally a key source of feedback in software designed for the Microsoft Windows and Apple Macintosh operating systems.

It is recommended that the feedback provided by the RVS prototype should be tested with naïve users. This should help to identify gaps and areas where clarity is lacking. Additionally, a status bar at the bottom of the screen would be beneficial to provide the user with feedback as they move the mouse cursor over the screen.

5.3.13 Help system

This section of the software evaluation chart concerns the design of the help system in software. The evaluation of the RVS prototype found that it does not include an on-line help system. This is a considerable deficit and leaves the user solely dependent upon the 13 page software manual. Virtually all proprietary health and safety software incorporates an on-line help system. The same is true for proprietary office software. The on-line help system is normally available as a constant reference source for the user.

If an on-line help system is developed for the final RVS software which is consistent with the user manual, the question will arise as to whether the on-line help system should be available in different languages. This point was touched upon in the earlier discussion concerning software manual design. An on-line help system that works in different languages may be necessary if the RVS software is to be used via the intranet across the multi-national sites of ESA, or if it is to be made available for use by other organisations. If the RVS software is intended to overcome language and cultural barriers, and to accommodate diversity, having the on-line help system in only one language would seem an unnecessary hindrance.

5.3.14 Printing

This section of the software evaluation chart concerns the quality of the printing functions of the software. Because of the length of time required to run printing tests, this part of the evaluation was not undertaken for the RVS prototype. It is recommended that the printing facilities of the prototype should be tested fully to provide input into the design of the final RVS software.

5.3.15 Security system

This section of the software evaluation chart concerns the design of the security system for software. The evaluation of the RVS prototype found that it does not include a security system. Barker (1998) argues that health and safety software should always incorporate a security system given the potential sensitivity of the data that may be stored within it. For example, data concerning employee health, insurance issues, and incident details. Nevertheless, Barker found that many proprietary health and safety programs fail to include a security system or feature only a very basic security system.

The notion of a security system is intriguing in the context of the RVS prototype. If the final RVS software is to succeed in widening participation in risk management by catering for a diverse group of users, and allowing them to interrogate freely data to inform their risk management decision-making, it would seem paradoxical to implement a security system that would serve as a barrier controlling access to information. This point will be explored further when conclusions are drawn in Chapter Six.

5.3.16 Software compatibility

This section of the software evaluation chart concerns the extent to which the software is compatible with proprietary office software, and existing risk management software at the organisation. Crucially, the evaluation found that the RVS prototype is compatible with the previous risk management databases at ESTEC. This is because the prototype was custom-made according to the author's detailed specifications and is based upon the author's original risk management databases. It means that it is possible to transfer data from the existing risk management databases at ESTEC into the RVS prototype.

This compatibility between the RVS prototype and the existing risk management databases at ESTEC differs considerably from proprietary health and safety software which is extremely unlikely to be compatible with organisations existing risk management databases. Typically organisations can import little existing data into new proprietary health and safety software (Barker, 1998). If data import is possible, it is usually only in the form of personnel records from other proprietary office spreadsheet or database software.

Another benefit of the RVS prototype is that it is possible to export data to proprietary office software. This task is relatively easy to accomplish. Data records can be exported in a standard text format that can be opened by a wide range of proprietary office software. This provides flexibility and intelligible output although the original formatting is lost. Data records can also be exported complete with formatting into the proprietary database program Claris

Filemaker Pro. Pictures from the Pictures database can be exported directly into Adobe Photoshop for photo-editing as was discussed in the section on data manipulation. Further, it is possible to 'copy' and 'paste' any data from the RVS prototype databases into any proprietary office software via the conventional Microsoft Windows and Apple Macintosh method. Overall, the RVS prototype has greater export possibilities than some proprietary health and safety programs.

5.3.17 Software Stability

This section of the software evaluation chart concerns the stability of software. The evaluation found the RVS prototype to have high stability. The prototype did not crash or become unstable during the intensive evaluation process. No errors were identified during the evaluation that may have been due to software instability. The RVS prototype was thoroughly tested in a multi-tasking environment using an Apple Macintosh laptop computer with 65MB RAM. As many as four other computer software applications were active simultaneously during the evaluation. If memory resources are low, the user of the RVS prototype receives standard Apple Macintosh warning messages. The stability of the RVS prototype is greater than that typically found in proprietary health and safety software. Software stability is particularly important if the final RVS software is to be implemented over the intranet.

5.3.18 Software Usability

This section of the software evaluation chart concerns the usability of the software. Overall the RVS prototype was found to be relatively easy to learn and use, except for the problems identified earlier in the evaluation regarding software installation, the keyword system, software manual, and the help system. The majority of the fore-mentioned problems can be rectified with little difficulty; the greatest challenge is posed by the keyword system. The RVS prototype responds reasonably intelligently to user commands and data entry. Further, as has been emphasised throughout the evaluation, its design offers considerable user control and flexibility. Proprietary health and safety software, in comparison, normally fares extremely poorly in this section.

5.3.19 Software Integration

This section of the software evaluation chart concerns how well the software can be integrated within the organisation. It considers this issue in terms of the level of informacy skills and risk management knowledge possessed by employees, and the risk management system of the organisation. As these points have been discussed throughout various sections of the evaluation, it is only necessary to summarise the findings here. Essentially, because the RVS prototype was designed according to the author's specifications, it matches exactly the ESTEC safety management system, computer hardware and operating systems, level of risk management knowledge and informacy skills of the risk management decision-makers of ESTEC. Needless to say, this is rarely the case with proprietary health and safety software.

5.3.20 Support Service

This section of the software evaluation chart concerns the support service that is provided for users of the software. With proprietary health and safety software which is purchased from external software companies, the quality of the support service is of paramount importance. The organisation who purchases this software is completely dependent upon the software company for a variety of reasons (see Barker, 1998). It is therefore essential that the software company is able to offer guidance and assistance in an appropriate format to organisations as and when required.

Because the RVS prototype was custom-made for ESTEC according to the author's specifications, ESTEC are effectively the 'owners' of the software.

There is unlikely to be a need for on-going support from the external software company that constructed the prototype. There is not the same degree of dependency between ESTEC and the software company as would be the case with a proprietary health and safety computer program.

A question does arise regarding support however if the final RVS software is to be utilised by multiple users across ESA sites. This diverse group would require a reliable support service in order to use the software to its maximum potential. The point was touched upon in the earlier discussion regarding the keyword system. Without such a support service, users may drift away from the RVS software when they encounter difficulties – they may cease to enter and analyse risk management data is the costs or difficulties and perceived to outweigh the benefits. There are clearly resource implications if a support service is to be provided for the RVS software. There are also questions concerning the exact form of support that should be provided, for example, telephone support lines, training and development programmes, an intranet or internet support site, or a support role for line management.

The question of a support service is also relevant if the RVS software is to be used or adapted by other organisations in the future. To what extent, if at all, would ESA provide guidance and support for these organisations? What are the implications for the future of the RVS software if guidance and support is not provided to encourage its use elsewhere? Are other organisations still likely to seek to adapt and implement the risk visualisation concept?

5.3.21 Software Company

This section of the software evaluation chart concerns issues related to the reliability of the software company. With proprietary health and safety software, because of the highly dependent relationship between the organisation using the software and the software company, the reliability of the software company and the quality of the service that they provide is of paramount importance. As was explained earlier in the evaluation, this is not the case with the RVS prototype.

5.4 Assessment of RVS Effectiveness

The previous section provided a detailed discussion of the findings of a systematic evaluation of the RVS prototype. The evaluation focused upon human-computer interaction issues, a comparison with proprietary health and safety software, and broader issues concerning software design and implementation. Whilst this evaluation is valuable and can offer guidance for refining the design of the final RVS decision support system, it does not attempt to address the question of the effectiveness of the RVS software in improving risk management communication and decision-making. As stated previously, this is primarily because there is not as yet a reliable method for evaluating the effects of decision support systems upon decision-makers. Therefore in this section, I will present a personal view on the effectiveness of the RVS prototype, based upon the feedback acquired from potential users during design and implementation. This qualitative assessment is intended to complement the discussion featured in the previous section.

There are three groups of potential users of the RVS prototype from whom feedback could be obtained. The first group consists of people external to ESA, such as other risk managers, managers, insurance companies, fire brigade inspectors, conference participants and working groups. This group of potential users do not know much about ESA's risk management models. RVS has proved to be a valuable tool that allows ESA's health and safety philosophy to be explained and demonstrated quickly and concisely to external parties. An example of this was provided in section 5.3.9 in the discussion concerning data manipulation, where RVS has been used to improve communication and demonstrate progress in risk management to a fire insurance company.

Another example of positive feedback from external parties is that received during lectures and presentations. The RVS prototype enhances the learning process, by making it easier to communicate information and explain risk management issues. Those who attend lectures at universities around the world may not have previous professional experience in risk management, and therefore may find it difficult to visualise risk management models, concepts and scenarios. The RVS prototype can improve their cognition.

The second group of potential users consists of people who are internal to ESA, are considered as experts and operate at the level of "leaders" (see Chapter Two). These staff are at the same level or higher in the organisational hierarchy to the risk manager. For example, experts in product assurance, safety officers from other ESA sites, and staff from the design office. This group of users have responded favourably to the RVS prototype. In particular, they have been impressed with the speed that they can find information based on only partial search criteria. This point was described in the discussion of the software evaluation findings in section 5.3.5.

The third group of potential users are other staff working at ESA but who fall into the category of "followers" (see Chapter Two). All of the security guards at ESTEC (approximately 50) have received basic safety training, and about 10 of them have been briefed on how to use the RVS prototype. As was explained earlier, the time horizon for these users is relatively short (only one or two years). This makes it difficult for them to consider the long-term picture for risk management at ESA, and to recognise the advantages of RVS. For this group of potential users, as was emphasised in section 5.3.5, the keyword system has proved difficult to understand and use. The difficulties with the keyword system were unanticipated and have led to improvements in the training process for sources using the RVS prototype.

5.5 Summary

In this chapter the two main objectives have been to explain in detail the design and construction of the RVS prototype, and to make an initial evaluation of the prototype by drawing comparisons with proprietary health and safety software. It is hoped that this chapter has demonstrated the substantial work and investment of resources that is required to develop a risk management DSS. The research has progressed from a position where there was no health and safety management system at ESTEC, to a position where a working RVS prototype has been constructed and evaluated. The journey from 'A' to 'B' has involved the development of the ESTEC Safety Management System model, the selection of suitable computer hardware and operating systems to support the development of a risk visualisation DSS, the creation of the original risk management databases, and the development of specifications for the RVS prototype.

The evaluation of the RVS prototype raised a number of intriguing questions and discussion points. Many of the problems that were identified can be rectified with relative ease, such as those concerning the design of the software manual, the help system, and the back-up facility. One of the major issues that emerged from the evaluation concern the difficulties that users experience with the current keyword system and the need for this to be simplified and tested with employees throughout ESA. Another major issue concerned the need for effective training and support to ensure that users understand fully the RVS DSS and risk visualisation concept. Practical recommendations were proposed for improving the design of the final RVS software.

The evaluation of the RVS prototype identified many points that are of benefit for understanding better the concept of a decision support system for risk management and what makes it distinct from proprietary health and safety software. The RVS prototype differs radically from the latter, offering far greater flexibility, adaptability, and user control. The RVS prototype is designed so that it can be fitted to the individual user rather than the individual user being stretched or restricted according to the constraints imposed by the software designer.

CHAPTER 6
CONCLUSIONS AND FURTHER WORK

6.1 Introduction

This chapter presents the findings of the research. It is structured by the broad disciplines that have informed the thesis: decision-making, decision support systems and risk management. In each case, the findings relevant to each discipline are present and further work discussed where appropriate.

6.2 Risk Management

In this research, risk management has been considered in the domains of health and safety, security and environmental protection.

6.2.1 Findings relevant to risk management

6.2.1.1 European ICT policy and risk management

Risk management practice has not yet embraced the philosophy presented in the European Commission's Green paper: Living and working in the information society: people first. RVS is a demonstration of how ICT can be creatively applied to achieving the ambitions of risk management. It is hoped that this will provide a case illustrative study for more applications to be developed.

6.2.1.2 Clarification of roles: Experts and decision-making

This research has emphasised the need to clarify the roles in organisations vis-à-vis risk management, and particularly, health and safety. The need for risk management expertise to be concentrated into specific individuals is a feature of considerable worth. However, the value is best realised for the organisation when this expertise is focussed to higher level problems such as strategy and recognising patterns and trends. This is not to say that there is not a role for the expert to provide support to decision-makers that may need the knowledge base and methodological skills of the experts. It is, however, to emphasise that it is the decision-makers that are generally best placed to identify and decide risk-related issues arising from their activities. For RVS to be truly useful, these roles in the risk management picture need to be clear to the organisation and the individual decision-makers with in.

The thesis paid particular attention to the concept of bifurcations and the need to identify the patterns of data arising from the organisation that signify their action. The role of the expert is indicated as crucial here and RVS is advocated as one tool to assist their efforts.

6.2.1.3 Models of Risk management as maps

Organisations wishing to develop a decision support system modelled on RVS will need to find correspondence between their own risk management and that of ESA. Firstly, it is hoped that the explicit links made between the ESTEC risk management model and established models will allow them to perform the equivalent mapping exercises. Clearly, the databases will be unique to each organisation. Secondly, any organisation wishing to take advantage of this research will need to consider any challenges to the assumptions made in RVS concerning the broad characteristics of ESA (see page 25). For example, an organisation that does not have a similar risk profile would need to consider the effect of the overall design.

6.2.2 Further work relevant to risk management

6.2.2.1 Impact of ICT upon decision-making roles

The implementation of RVS into the wider ESA organisation will need to proceed with appropriate methods of change-management in place. This would be prudent for any innovation but is particularly necessary here because of the hypothesised effect of RVS upon power and control of information. The general impact of ICT innovations is "empowering" and tends to flatten hierarchical organisations because of the improvement in lateral communication across the lines of command.

6.2.2.2 Effectiveness of RVS as communication support

RVS provides support to the expert in interaction with individual decision-makers by supplying props for communication. RVS is believed to be successful here but further work is required to assess the effectiveness of the system in this respect.

6.2.2.3 The impact of different organisational characteristics

As indicated above, generalising the RVS design to other organisations involves visiting the basic assumptions made about the characteristics of the organisation, including its risk profile. Further work could explore the impact of different risk profiles upon the design of DSS for risk management.

6.2.2.4 Alarms & Triggers to decision-making

RVS is likely to be used for non-routine aspects of a person's work. The idea of pseudo-decisions was introduced to clarify the idea that routine situations may require decisions but with very low levels of uncertainty. Hence pseudo-decisions are made with little conscious thought on the part of the deciding agent. However, Rasmussen (1997) has demonstrated that it is the incremental effects of small "routine" changes in practices and methods of work that "migrate" an organisation towards the boundary of safe operation. Hence major bifurcations may be set up that are not detected and responded to. This raises the question of how systems like RVS can be of assistance. One area for development is of "Alarms" to be set up in RVS (this is considered further under the heading of decision-making. A second approach comes from changes in motivations and styles of interaction with DSS technologies like RVS. As the EC Green paper (EC, 1996) makes clear, *informacy* is now and will increasingly be emphasised as a key life skill. It is imaginable that recreational use of DSS systems will provide the monitoring (for bifurcations) that this thesis has argued as necessary.

The last issue here is the implications of mathematical/computational advances in handling "problems of organised complexity". This relates to both sides of the coin: on the one face, risk management in organisations and, on the other, decision-making. The implication here is to more closely align research in risk management with research on this issue in mathematics and computer science. In this respect, the work of Casti (1997) serves as an example.

6.3 Decision support systems

In this research, decision support systems have been looked at theoretically and also practically through the development of a prototype.

6.3.1 Findings relevant to decision support systems

This research shows that DSS technology can be applied to risk management and this thesis has documented the issues that need to be addressed to this. A number of findings are highlighted.

6.3.1.1 Managing complexity through black-boxes

RVS is reliant on the quality and quantity of data inputted by its Sources (the people who introduce new cases to RVS databases). One finding is the need to train Sources to attach more keywords than they may judge are strictly necessary for their own retrieval of a given case. This is particularly true of the second coding of keywords in RVS. An approach used in this research, that is advocated to other DSS applications, is the use of people to interpret complex data at the input stage which has been described here as deploying the black-box complexity of the Source to match the complexity of the situation to be recorded. The issue here is that whilst one cannot dive into the black-box (because of its complexity) one can regulate its behaviour through its inputs and outputs. Hence there is a training and calibration role for the DSS designer in this respect.

6.3.1.2 DSS and visualisation

This research has advocated information visualisation as an appropriate means of promoting the purposes for which DSS technology is advocated. Essentially, both visualisation and DSS aim to assist the clarification of assumptions and improvement of data search by decision-makers. The information visualisation methods used in RVS are relatively modest compared to what seems possible. The limits have been the complexity of risk management data and the level of hardware required to support the more sophisticated technologies reviewed here (see page 137). What this research makes clear is the need for DSS research to incorporate information visualisation into the mainstream of its thinking.

6.3.1.3 The importance of diversity

Cultural and technological diversity is theme that runs through this thesis. One strategic finding is that the diversity is a creative resource if integrated through an appropriate means to access such as browsing. This is in distinction to rigid database architectures that impose the need to standardise fields and keywords.

This finding is of importance to decision support systems that link different users together and, hence, promote communication of an asynchronous type. Where people do not share the same culture or technical background the opportunity exists to see different and creative possibilities in the difference of perspective that this provides. However, there are certain limits on this if keywords are relied upon, and here the use of a picture database is advocated as a means of removing ambiguity and supporting meaning.

6.3.1.4 Design Criteria from CSCW apply to DSS development

Another connection made though this research has been the realisation that DSS systems can sometimes be regarded as "groupware" or examples of CSCW. The impact of this is twofold. First, the design criteria for CSCW (e.g. the "what-you-see-is-what-I-see", WYSIWIS, criterion) should be applied where a DSS shares data between users. Also, there technologies developed to support CSCW may well provide functionality not otherwise recognised for DSS (e.g. synchronous use of a DSS from two or separate locations). The group-use of DSS is the subject of further comment below.

6.3.1.5 Information security considerations

Information security was not taken into consideration in this research – it was not necessary at the prototype stage. However, for others considering this technology, security concerns do need to be accommodated. This is likely to be manifest in two main ways. First, individual decision-makers may be inhibited from using DSS's because they are uncertain about the integrity of the data storage (what-you-see-is-what-everybody-sees!). The second issue is the legitimate concern of an organisation to protect its intellectual property. Clearly, DSS of the RVS type emphasises the sharing of experience and know-how and this may sometimes be an incompatible motivation with security. The solution is identify and involve stakeholders at the design stage and to ensure monitoring and review with security interest uppermost.

6.3.2 Further work relevant to decision support systems

The prototype produced during this research was subject to expert comparison to proprietary health and safety software. This was instructive but further work is required to benchmark RVS against other DSS's.

6.3.2.1 Balancing automation with autonomy: benefits of DSS "intelligence"

The support provided by a DSS can be enhanced by incorporating a further degree of "intelligence" to such systems. Such functionality would aim to give increasingly active support to the user. For example, the system - by monitoring the users search terms and patterns of browsing - could suggest related topics automatically. At a yet higher level, an intelligent DSS could help provide feedback on the strategies adopted by the decision-maker either during the "live" session or afterwards as a training tool. However, the "do no harm" criterion needs to be kept in view – greater active support from the DSS may tend to adversely interfere with the outcome of decisions and this should be guarded against.

If intelligence of the type described were provided, it becomes possible that data about decision-making can be recorded. This could be a means for delivering valuable (and currently missing) data to researchers of the effectiveness of decision support systems and to research into decision-making generally.

Without "intelligence" it is entirely possible to log DSS use and feedback the data to the system designer. The purpose would be to discover which functions and data-sources are under-utilised. This would allow the reasons to be explored and appropriate training or redesign undertaken.

6.3.2.2 The need for a review of DSS developments in the private sector

The literature survey revealed a lack of published examples of decision support systems. A large-scale survey is urgently required to identify the current state of development in this technology. In keeping with the EC policy of ICT, this should certainly aim to share approaches as widely as commercial interests allow.

Expanding keyword access: the role of automatic pattern recognition

RVS relies heavily on users inputting more keywords than are strictly necessary for the purposes of their own retrieval. For example if a file were only for one's own use, a memorable file name would suffice; clearly that this would not help other people find the file. This is particularly true of the second level of encoding, where key words are required denoting aspects of the environment, equipment or activity of a more general nature than the incident, audit or inspection that has cued the record to be made.

A future development, with a great impact on RVS, would be automatic pattern recognition of elements in photographs submitted to the system. Functionality of this type would allow key words to be generated automatically, taking away the workload from the user, instead using their understanding of the context to check the validity of the key words generated. Clearly this time for technology would work very well in any DSS that uses graphical input.

6.3.2.3 Simulation

At the moment, RVS supports users to develop simulations in the user's mind: visualisation. However, it is conceivable that simulation in the machine may become a more practicable function than is possible now. At present, the two limiting factors are the complexity of data and the computational difficulty of simulations of this type. Nonetheless, DSS research should seek to incorporate simulation whenever possible as this would allow decisions to be tested before implementation.

6.4 Findings relevant to Decision Making

6.4.1 What initiates decision-making?

A feature of this work has been to support people in the process of developing a decision. However, what triggers decision-making has been left largely implicit. The model proposed by Salengros (1999) applies when a decision is happening or has happened but not to predict when this type of behaviour may occur; why do people make decisions? This work has concentrated on the need to support pattern recognition particularly that of the Risk expert in their role as the detector of bifurcation. Here, the expert is scanning for the need to act upon the system in the light of changes occurring to which an adaptation is required. It is possible however, to imagine an alarm feature for RVS; that the system should, in effect, a prompt with "here is something that you need to know"

6.4.2 DSS as a trigger to decision-making

One can see an alarm system been operated in a number of ways. The simplest is where the would-be decision-maker selects incidents, of a type or involving the technology of interest to him or her. The next, which involves a little more sophistication, is where the system learns the interests of the decision-maker through monitoring system use during previous sessions with RVS. An elaboration of this would be to program the system with a biographical and functional (in terms of the organisation) details of the user that may form the basis of a "need to know" automatic selection of new cases or of trended data.

6.5 Findings relevant to the Generalisation of this work

6.5.1 Generalising the prototype to a wider family of users

In the present work the emphasis has been upon the Risk expert as the user of this first generation of RVS. However, throughout the thesis it has been clear that decision making in risk management can involve anybody. Rasmussen's (1997) hierarchy of regulation shows that, although decisions are a prime source of latent failures, the decision-makers are not just managers but may be anyone from the shop floor upward. In order to implement RVS more widely into the agency, appropriate efforts must be made to fit RVS to the variety of users and uses. In other words, "to accommodate diversity". In practice this means that the variety of user characteristics must be assessed and their impact upon RVS design understood and accommodated. Accommodation may be influenced by both the design of the RVS interface and, perhaps, the data sources available through RVS. Ideally, RVS should be introduced at the level of the workforce (rather than of the managerial level), however this would need careful study to ensure a good fit between RVS and the user, their environment and their needs for data.

6.5.2 Group decision-making and RVS

It has been argued that the asynchronous mode of communication is facilitated via RVS; what of synchronous decision-making? Group dynamics add an important dimension to be accommodated in the design of a DSS, as does the variation of a group in the same space versus a group scattered geographically but in communication via RVS. Further work is required to evaluate RVS performance and identify the design criteria that need to be accommodated for support of group decision-making.

6.5.3 Generalisation of RVS to organisations other than ESA

The next order of generalisation is to different organisations. Firstly, in this thesis attempts have been made to link the ESTEC model of risk management to general models of risk management that are more widely known and accepted. It is hoped that organisations interested in implementing their own version of RVS may "map" their risk management systems to the same general models and so achieve correspondence between the model used at ESTEC and their own. Another issue which stands between RVS as used in the agency and other organisations, is the set of characteristics noted in chapter one. All that could be said at present is that an organisation wishing to use a DSS based on RVS is that they should match these characteristics of risk profile, cultural diversity, pace of change etc. The issue for further work is the extent to which one can challenge these assumptions without altering the basic RVS idea.

6.5.4 Generalisation of RVS other platforms

Another issue is how to generalise RVS to different computer platforms – to increase the portability of the system. In this study we have developed RVS for Apple Macintosh and for PCs. However, it is now conceivable that a platform-independent (i.e. inter-operable) version could be produced using internet technologies such as JAVA etc.

6.5.5 Generalisation to other domains of risk

In its current form, RVS could be easily be extended to cover domains of risk such as food safety and transport. This is because these domains are also object-based; meaning there is a concrete reality that can be observed, photographed etc. What is more challenging is the application of RVS to domains such as finance, or IT security where the risks are to more abstract entities such as money and data. Another feature that RVS would benefit from - in any domain of application - is the use of graphical visualisation techniques such as those of SPIRE (Thomas, ibid.).

6.5.6 DSS and with a database of prior solutions

The functionality of RVS could be extended via Case-Base Reasoning technology. This would allow solutions to problems (e.g. recommendations made in the light of incidents and audits) to be retrieved more quickly than browsing alone. This would involve the computer prompting the user for features of the current situation (e.g. the technology, activity, and location) and returning closely matching cases from the RVS databases.

6.5.7 Diversity as a criterion for future DSS design

The generalisation of RVS in the ways indicated, and it is suggested that this is true of any DSS, is always likely to invite standardisation. This is because standardised formats for databases and data make life easier for the IT developer and, apparently, to the end user too. However, whilst it is good HCI design to provide "user friendliness", this needs to be balanced with functionality. One of the themes running through this work has been diversity; it is thought to be a key attribute in promoting decisions informed by viewpoints other than the decision-maker and his immediate circle. Therefore, an important message from this thesis to ICT design in general, is that designers should seek to preserve diversity by integrating different data sources rather than standardising; speaking many languages, as it were, rather than insisting on just one. In RVS, the picture database transcended diversity of language (but not necessarily the full diversity of technical backgrounds). It is hoped that the incorporation of a technical dictionary and thesaurus will provide equivalent integration of different languages and terminology; these would allow browsers to view terms connected semantically, opening a further dimension of access.

6.5.8 Risk management and implementation of ICT

The previous chapter discussed the restricted nature of much health and safety software and, together with the rest of this thesis, has sought to make a case for innovative use of ICT in risk management. However, two research needs are noted here.

First, as noted in Chapters Two and Three, the introduction of ICT of any sort has an impact upon the structure of power and influence in the organisation. In risk management where, traditionally, experts have had authority for decision-making on risk issues such as health and safety and the introduction of software such as RVS may be perceived with mixed feelings. For instance, negative perceptions might include threat to their authority and a weak link in their control of information. More positively, that might see RVS has a means of extending their influence and enhancing the service they offer to the organisation. Equally, in settings where a rule-based approach is taken to health and safety, line staff may well not want the responsibility that the RVS concept assumes is desirable in effective risk management. Research is needed to provide methods to analyse the network of communication and influence for any given domain of risk management (such as health and safety) within and organisation. Such a method could be of assistance to both practice (e.g. change management of ICT implementation) and research (the nature of the change process and the qualitative and quantitative effect upon risk management). More generally, this might also provide much needed practical data about the effectiveness of decision support systems and of the validity of the NDM perspective of decision-making.

Second, a method of analysis as described might be usefully applied to characterise the roles and positions likely to be significant when implementing ICT risk management support in organisations. Thus, even if organisations do not invest in analysis, they may have the advantage of targeting key personnel for training, counselling and involvement in design and implementation processes.

6.6 Final Thoughts

Starting in September 2000 a new function as Security and Risk Management Co-ordinator at ESA, Paris headquarters, I would like to emphasise the fact that the conclusions of this research will be very useful to propose a fresh efficient vision for ESA corporate risk management. This intellectual odyssey is finished after five years voyage but the adventure will continue.

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LIST OF ABBREVIATIONS

BS8800	British Standard 8800: Occupational Health and Safety Management
CHI	Computer to Human Interface
CSCW	Computer Supported Co-operative Work
CSE	Cognitive System Engineering
DA	Deciding Agent
DBMS	Database Management System
DGMS	Dialogue Generation and Management System
DSS	Decision Support System
EAC	European Astronaut Centre
EC	European Commission
ELDO	European Launcher Development Organisation
ESA	European Space Agency
ESOC	ESA Site in Germany
ESRIN	ESA Site in Italy
ESRO	European Space Research Organisation
ESTEC	European Space Research and Technological Centre ESA Site in the Netherlands
EURO	European Currency
HCHI	Human Computer Human Interaction
HCI	Human to Computer Interface
IC	Information Communication
ICT	Information and Communication Technology
IT	Information Technology
KISS	Keep It Simple and Stupid
LAN	Local Area Network
LC	Life Cycle
MBMS	Model Base Management System
MIT	Massachusetts Institute of Technology
NASA	National Aeronautics and Space Administration
NDM	Naturalistic Decision-Making
PC	Personal Computer
RAS	Risk Assessment Study
RM	Risk Management
RVS	Risk Visualisation System
SDS	Substantive Decision Support
SRK	Skill, Rule and Knowledge
UK	United Kingdom
USA	United States of America
USNRC	United States Nuclear Regulatory Commission
UT	Underlying Technologies