Fuzzy Logic in Management

INTERNATIONAL SERIES IN
OPERATIONS RESEARCH & MANAGEMENT SCIENCE
Frederick S. Hillier, Series Editor Stanford University

Balsamo, S., Personé, V., & Onvural, R./ *ANALYSIS OF QUEUEING NETWORKS WITH BLOCKING*
Bouyssou, D. et al. / *EVALUATION AND DECISION MODELS: A Critical Perspective*
Hanne, T. / *INTELLIGENT STRATEGIES FOR META MULTIPLE CRITERIA DECISION MAKING*
Saaty, T. & Vargas, L. / *MODELS, METHODS, CONCEPTS and APPLICATIONS OF THE ANALYTIC HIERARCHY PROCESS*
Chatterjee, K. & Samuelson, W. / *GAME THEORY AND BUSINESS APPLICATIONS*
Hobbs, B. et al. / *THE NEXT GENERATION OF ELECTRIC POWER UNIT COMMITMENT MODELS*
Vanderbei, R.J. / *LINEAR PROGRAMMING: Foundations and Extensions, 2nd Ed.*
Kimms, A. / *MATHEMATICAL PROGRAMMING AND FINANCIAL OBJECTIVES FOR SCHEDULING PROJECTS*
Baptiste, P., Le Pape, C. & Nuijten, W. / *CONSTRAINT-BASED SCHEDULING*
Feinberg, E. & Shwartz, A. / *HANDBOOK OF MARKOV DECISION PROCESSES: Methods and Applications*
Ramík, J. & Vlach, M. / *GENERALIZED CONCAVITY IN FUZZY OPTIMIZATION AND DECISION ANALYSIS*
Song, J. & Yao, D. / *SUPPLY CHAIN STRUCTURES: Coordination, Information and Optimization*
Kozan, E. & Ohuchi, A. / *OPERATIONS RESEARCH/ MANAGEMENT SCIENCE AT WORK*
Bouyssou et al. / *AIDING DECISIONS WITH MULTIPLE CRITERIA: Essays in Honor of Bernard Roy*
Cox, Louis Anthony, Jr. / *RISK ANALYSIS: Foundations, Models and Methods*
Dror, M., L'Ecuyer, P. & Szidarovszky, F. / *MODELING UNCERTAINTY: An Examination of Stochastic Theory, Methods, and Applications*
Dokuchaev, N. / *DYNAMIC PORTFOLIO STRATEGIES: Quantitative Methods and Empirical Rules for Incomplete Information*
Sarker, R., Mohammadian, M. & Yao, X. / *EVOLUTIONARY OPTIMIZATION*
Demeulemeester, R. & Herroelen, W. / *PROJECT SCHEDULING: A Research Handbook*
Gazis, D.C. / *TRAFFIC THEORY*
Zhu, J. / *QUANTITATIVE MODELS FOR PERFORMANCE EVALUATION AND BENCHMARKING*
Ehrgott, M. & Gandibleux, X. / *MULTIPLE CRITERIA OPTIMIZATION: State of the Art Annotated Bibliographical Surveys*
Bienstock, D. / *Potential Function Methods for Approx. Solving Linear Programming Problems*
Matsatsinis, N.F. & Siskos, Y. / *INTELLIGENT SUPPORT SYSTEMS FOR MARKETING DECISIONS*
Alpern, S. & Gal, S. / *THE THEORY OF SEARCH GAMES AND RENDEZVOUS*
Hall, R.W./*HANDBOOK OF TRANSPORTATION SCIENCE - 2nd Ed.*
Glover, F. & Kochenberger, G.A. / *HANDBOOK OF METAHEURISTICS*
Graves, S.B. & Ringuest, J.L. / *MODELS AND METHODS FOR PROJECT SELECTION: Concepts from Management Science, Finance and Information Technology*
Hassin, R. & Haviv, M./ *TO QUEUE OR NOT TO QUEUE: Equilibrium Behavior in Queueing Systems*
Gershwin, S.B. et al/ *ANALYSIS & MODELING OF MANUFACTURING SYSTEMS*
Maros, I./ *COMPUTATIONAL TECHNIQUES OF THE SIMPLEX METHOD*
Harrison, Lee & Neale/ *THE PRACTICE OF SUPPLY CHAIN MANAGEMENT: Where Theory And Application Converge*
Shanthikumar, Yao & Zijm/ *STOCHASTIC MODELING AND OPTIMIZATION OF MANUFACTURING SYSTEMS AND SUPPLY CHAINS*
Nabrzyski, J., Schopf, J.M., Węglarz, J./ *GRID RESOURCE MANAGEMENT: State of the Art and Future Trends*
Thissen, W.A.H. & Herder, P.M./ *CRITICAL INFRASTRUCTURES: State of the Art in Research and Application*

**** A list of the early publications in the series is at the end of the book ****

FUZZY LOGIC IN MANAGEMENT

CHRISTER CARLSSON
IAMSR, Åbo Akademi University
Åbo, Finland

MARIO FEDRIZZI
Department of Computer and Management Sciences
University of Trento, Trento, Italy

ROBERT FULLÉR
Department of Operations Research
Eötvös Loránd University, Budapest, Hungary

Springer Science+Business Media, LLC

Library of Congress Cataloging-in-Publication Data

A C.I.P. Catalogue record for this book is available from the Library of Congress.

FUZZY LOGIC IN MANAGEMENT, by Christer Carlsson, Mario Fedrizzi, Robert Fullér.
ISBN 978-1-4613-4744-6 ISBN 978-1-4419-8977-2 (eBook)
DOI 10.1007/978-1-4419-8977-2

Printed on acid-free paper.

Contents

List of Figures

List of Tables

Introduction

The developement of fuzzy logic was motivated in large measure by the need for a conceptual framework which can address the issue of lexical imprecision. Some of the essential characteristics of fuzzy logic relate to the following [2]: (i) In fuzzy logic, exact reasoning is viewed as a limiting case of approximate reasoning; (ii) In fuzzy logic, everything is a matter of degree; (iii) In fuzzy logic, knowledge is interpreted as a collection of elastic or, equivalently, fuzzy constraints on a collection of variables; (iv) Inference is viewed as a process of propagation of elastic constraints; and (v) Any logical system can be fuzzified.

There are two main characteristics of fuzzy systems that give them better performance for specific applications: (i) Fuzzy systems are suitable for uncertain or approximate reasoning, especially for systems with mathematical models that are difficult to derive; and (ii) Fuzzy logic allows decision making with estimated values under incomplete or uncertain information.

Numerous books have been written about management and there are also numerous models and theoretical frameworks for how successful management principles should be implemented and carried out in practical activities.

Some of the best insights in the field were summarized by Steen Hildbrand and Erik Johnsen (1994) [1]: "we know more (about management) than we believe, but we use less of what we know than we should". They use Danish management challenges and principles as their context and bring out the observations that successful companies should (i) master effectiveness and quality in both the details and the whole, (ii) build on and work with flexibility, and should (iii) support continuous learning in both the organizational and the individual level. Understanding and mastering all these components in a dynamic and sometimes drastically changing environment is often classified as complicated, sometimes as impossible.

In this monograph we want to show that the complexity of management can be reduced and that the changes of the environment can be more easily handled by bringing fuzzy logic into the management models and into the practice of management. The book is organized as follows. It begins, in Chapter 1 "Management and Intelligent Support Technologies", with a short survey of leadership and management activities in order to set the stage for what should be expected from support technologies and progresses through an analysis of the potentials and the limitations of these technologies.

In Chapter 2 "Fuzzy Sets and Fuzzy Logic", we provide a short introduction to fuzzy sets, fuzzy relations, the extension principle, fuzzy implications and linguistic variables.

Chapter 3 "Group Decision Support Systems" deals with some issues related to group decision making, and we describe some methods for supporting the consensus reaching processes. In the basic framework, we have a set of individuals, who present their opinions concerning an issue in question, and a chosen mediator, called the moderator, who is monitoring and managing the session with the individuals. The individuals present their alternatives, opinions or arguments, which may initially differ significantly, i.e. the group, may be far from consensus (or a unanimous agreement). Then, the moderator - via some exchange of information, rational argument, bargaining, etc. - tries to persuade the individuals to change their opinions. If the individuals are rationally committed to consensus, such a change usually occurs, and the group gets closer to consensus. This is repeated until the group gets sufficiently close to consensus, i.e. until the individual opinions become sufficiently similar, or until we reach some time limit decided for the process.

It is clear, that if the number of individuals is large enough and the structure of their opinions is complex enough (as it will be in our case), then it may be difficult for the moderator to assess how close is the group to consensus, and, consequently, to run the session efficiently. Thus, the moderator somehow should be able to measure consensus degrees. We will show that this can be successfully implemented by introducing the principle of a soft degree of consensus, some elements of commonsense knowledge and natural language, which ar e brought together in an interactive mode for communications. In the Section "An Interactive System for Supporting Consensus Reaching" we briefly show how to operate this menu-driven system by man-machine interactions.

Chapter 4 "Fuzzy Real Options for Strategic Planning" summarizes our results in the Waeno research project, where the *fuzzy real options* *theory* was implemented as a series of models, which were built on Excel platforms. The models were tested on a number of real life investments, i.e. real (so-called) giga-investment decisions were made on the basis of the results. The methods were thoroughly tested and validated in 2001. Then the models were enhanced with the theory of fuzzy sets and the classical Black-Scholes formula was extended to work with fuzzy numbers. The new series of models, for fuzzy real option valuation (ROV), have been tested with real life data and the impact of the innovations have been traced and evaluated against both the traditional ROV-models and the classical net present value (NPV) models. The fuzzy real options were found to offer more flexibility than the traditional models; both versions of real option valuation were found to give better guidance than the classical NPV models. The models are being run from a platform built by standard Excel components, but the platform was enhanced with an adapted user interface to guide the users to both a proper use of the tools and better insight. A total of 8 actual giga-investment decisions were studied and worked out with the real options models.

The results of the Waeno research program on giga-investments were evaluated and discussed in an international workshop at IAMSR on May 6-8, 2002. The workshop participants included (i) researchers, (ii) corporate managers, experts and planning staff, (iii) consultants, and (iv) systems and software developers. The objectives of the workshop were to find both a state-of-the-art on handling giga-investments, the use of real options theory for investment decisions and to find promising areas for further research. The fuzzy ROV-model was presented and met with both criticism and (finally) cautious appreciation by the participants of the workshop. Key parts of the fuzzy ROV theory and models have been published in several journals.

In Chapter 5 "Soft computing methods for reducing the bullwhip effect" we summarize our findings in the EM-S Bullwhip research project. The research work focused on the demand fluctuations in paper mills caused by the frictions of information handling in the supply chain and worked out means to reduce or eliminate the fluctuations with the help of information technology. The program enhanced existing theoretical frameworks with fuzzy logic modelling and built a hyperknowledge platform for fast implementation of the theoretical results. The first results required a revision of the fuzzy number theory, which was carried out successfully and was subsequently published in the *Fuzzy Sets and Systems* journal. The theoretical work produced a program for eliminating the bullwhip effect, which turned out to be quite good and was implemented.

In Chapter 6 knowledge management is worked out as an area for implementing intelligent information systems and it is shown that there are some possibilities to work on the collection, storing, transfer and management of knowledge with fuzzy logic. The principles are worked out in detail with software agents, which are used for searching and scanning in data sources and for organizing and storing material in data warehouses. The true challenge is the summarizing, sense-making and interpretation of data to produce knowledge, if we want this to be done with information technology. We show that there is some potential for this with fuzzy logic.

Finally, in Chapter 7 we introduce some applications of mobile technology by first showing empirical facts about the use of mobile technology in Finland, Hong Kong and Singapore and, secondly, showing that the applications are information systems, which can be supported with software agents. There is gradually emerging some consensus in the field that advanced, value-adding mobile services will need intelligent support both in the user interface and in the infrastructure, and that this support would much benefit from fuzzy logic. There are some ideas and proposals that these support functions will be part of the emerging 3G mobile technology.

References

[1] Hildebrand, S. and Johnsen, E., *Ledelse nu* (Management Now), Borsen Boger, Copenhagen 1994.

[2] Zadeh L.A., Knowledge representation in fuzzy logic, In: Yager R.R. and Zadeh L.A.eds., *An Introduction to Fuzzy Logic Applications in Intelligent Systems* (Kluwer Academic Publisher, Boston, 1992) 2-25.

Chapter 1

MANAGEMENT AND INTELLIGENT SUPPORT TECHNOLOGIES

We live in a world in which information and communication technologies (ICT) are becoming a ubiquitous presence in our working day. In most cases the impact and influence are benevolent and we should be looking for ways to improve the productivity of our working time with the help of ICT driven tools and support systems. In some cases it has turned out that the technologies become a problem as they are only partly mastered, as the learning process requires resources and time, and as the introduction of the ICT applications themselves have an adverse impact on the productivity of everyday working time.

We will tangle with the discussion of leadership versus management in Chapter 2, so here we will as briefly as possible just introduce a vague outline of what is involved in leadership and management activities in order to set the stage for what should be expected from support technologies. The key appears to be: (i) to understand, in some context, what needs to be done, (ii) then, what could be done to make a difference, (iii) then, to understand what actions and/or activities will produce performance and results, and (iv) what are the impact and relevance of the performance and results on the goals and in the context of actions and activities.

In recent years a number of innovative applications of modern support technology have been presented and published in international conferences[1]. The challenge for future research is still to explore and understand both successes and failures with the innovative and more advanced intelligent systems constructs.

[1]Such as the HICSS, INFORMS, IFORS, EURO, DSI, ICIS and ECIS conferences

It is a truism in the field that the key problems never appear to be technology related, but they are "people problems": (i) people have cognitive constraints in adopting intelligent systems, (ii) people do not really understand the support they get and disregard it in favour of past experience and visions, (iii) people cannot really handle large amounts of information and knowledge, (iv) people are frustrated by theories they do not really understand, and (v) people believe they get more support by talking to other people (even if their knowledge is limited).

We will use the lessons learned from implementing hyper knowledge as a support platform for strategic management in order to discuss how support technology may be enhanced with new results in intelligent systems and soft computing.

This small wedge in the complex set of issues which form the discussion of intelligent support technologies, the potentials and the limitations of these technologies, the use responsible managers may want and actually intend to make of emerging technologies and the possible impact they may have on actual management processes, will be used to set the scene for the broader and deeper impact we expect fuzzy logic to have in management.

1. Management

Management is about making things happen in ways which make sense to those involved in the actions and activities, and to those who are influenced by the outcomes of these actions and activities. The making sense is understood in several different ways depending on the context and the culture, but it is safe to say that rationality should be involved when we judge if actions and activities make sense or not.

If we base things on rationality, we can simply state that actions and activities make sense if they improve some values - in a social context they make us feel better or they make those influenced by the outcomes feel better. In a corporate context the values involved would mean improved profitability, reduced costs, improved productivity, reduced commitment of working capital, improved market share, reduced downtime, improved sustainable competitive advantages, reduced plant shut-downs, improved return on assets, etc. In the corporate context there is normally a much larger number of ways we want to define the improvements of value than in a social or a personal context.

If we leave leadership aside for a few moments and focus on management as the force behind "making things happen" - then (cf. [18]) "all managerial activities revolve around decision making". We are well aware of the fact that this is not a complete truth, and we will make amendments in Chapter 2, but let us stay with this thought as a basis for the coming discussion of decision support systems.

Turban (in [18]) quotes the results of a study aimed at finding good management practices, which was carried out with 6500 managers from more than 100 companies as they entered a training course at Harbridge House: the ability rated first in importance was to make crisp decisions, ranked second was the ability to get to the heart of problems and most of the remaining eight key management practices (among the top ten) were more or less related to decision making.

In the Kepner-Tregoe (cf. [28]) survey on speed and quality in decision making, which was carried out with 818 managers and workers[2] in a cross-section of U.S. industries in 2000, a number of interesting observations emerged. About 70% reported that they have to make an increasing number of decisions in the same time or less (as compared to three years before), that they have to make an increasing number of decisions each workday. More than 80% believed that top management in their organizations are unable to make timely decisions and that opportunities are missed as a result, and almost 70% had found that decisions they make will fail because they are not implemented quickly enough due to organizational inertia.

However, fast decision making is not always the same as good quality decision making. Both managers and workers had seen quality suffer when speed became the primary driver of decision making - the key reasons for bad decision making under pressure was poor information sharing, failure to involve the right people, failure to agree up front on what should be accomplished and not gaining commitment to a decision before implementing it. IT has become the main and most important source of information for decision making with e-mail, shared documents, Internet and other web-based solutions being the major sources. The virtual world is growing in importance as the context for decision making and is reducing the reliance on personal meetings.

About 60% of the respondents said that the shift to virtual information sources had had a positive effect on the speed and quality of decision making. Still about 25% had found that information technology either had no impact or a negative impact on their decision making; about 50% said that wireless technology has no impact on the speed and quality of decision making and only about 30% use artificial intelligence (or similar intelligent technologies) and only about 10% believe that it ahs increased the speed and quality of decision making. There is not much of a case

[2]The number of returned questionnaires

for advanced technology but the increasing use of virtual information sources gives a good starting point for introducing intelligent tools as a means for enhanced support.

Organizations are not good at collecting and reusing their experience in making good decisions - about 90% of the respondents said that their organizations do not maintain a database of past decisions and 80% said that there is no common framework for (good) decision making, which would be used throughout the organization. Most decision making is done in groups and in a majority of cases with people from different locations, but the technology used to support these activities remains fairly basic: e-mail, teleconferencing and videoconferencing.

This view of the decision making context supports Turban's description (cf. [29]) that (i) advancements in information and computation technologies (communication technology should be added) will produce more decision alternatives to choose from; (ii) increasing competition and a growing structural complexity in industrial sectors will contribute to larger costs of making errors; (iii) increasing changes in international markets, a decreasing political stability overall, increasing consumerism and increasing government interventions will produce more uncertainty about the future, and (iv) increasing changes and fluctuations will require quick decision making.

These arguments are today (as in the late 1970's) supporting the use of decision support technologies for better decision making, even if the focus and the actual technologies used have evolved and changed with changing generations of information technologies.

2. Decision Support Systems

It is, in fact, easy to verify that standard DSS methodology [18] rather closely resembles standard operations research methodology [27] - the original intention was actually to supplement OR/MS modelling with DSS modelling [18].

There has also been some fallacies in the field over the years [6]: (i) the people we think of as decision makers in an organisation appear not to be using computer-based systems - the DSS are something used by staff people charged with getting data and information for the decision makers; (ii) we did not in time realise that it is counter-productive to give executives tools for carrying out tasks they normally do not perform at all.

As senior managers - the actual decision makers - did not become active DSS users they were replaced as active DSS users by junior analysts, market analysts, financial planners, controllers, etc. - staff people who do not necessarily have the knowledge, experience, visions and overview to fully utilise the potential of a DSS for significant decision support [6]. Then it is not surprising, that we have not seen too many cases where senior decision makers and computer-based support systems have tackled complex problems in interaction, and that we have not been able to show that a resulting synergy has produced new, innovative solutions [1]. Thus, something has gone rather wrong with the standard DSS approach and the promised more effective and productive way to deal with non-structured problems has not become a reality.

As could be expected there were reactions to these problems and we got the movement towards the *active or intelligent DSS.*

The need for an active DSS was shown by Keen [10], when he outlined the "the next decade of DSS" (in 1987). His first point was that the DSS as such is not important it is the *support* we intend to provide which is the key element.

Keen gave DSS research the following broad agenda: (i) research should look for areas where the proven skills of DSS builders can be applied in new, emergent or overlooked areas; (ii) it should make an explicit effort to apply analytic models and methods; it should embody a far more prescriptive view of how decisions can be made more effectively; (iii) it should exploit the emerging software tools and experience base of AI to build semi-expert systems, and (iv) it should re-emphasise the special value of DSS practitioners as they have the unique combination of expertise in understanding decision making and knowing how to take advantage of developments in computer-related fields. Keen's first three points show the direction to an active DSS.

The term *active DSS* is not really new - it has actually been used by a number of authors. Manheim wanted the DSS to play an active role in dealing with tasks in problem solving which are ambiguous and complex; this active role should be "to take the initiative without getting specific orders" and an ability "to respond to non-standard requests and commands". Mili wanted an active DSS for (i) understanding the domain ($\approx$ to provide explanations); (ii) problem formulation ($\approx$ to determine assumptions and abstract reality); (iii) relating a problem to a solver ($\approx$ to assist with proper problem-solver interaction, to advise on proper procedures); and to (iv) interpret and (v) explain results and decisions (cf. [17]). Anghern [1] makes the case for an active DSS and introduces a conversational, agent-based approach to DSS in order to 'enhance creativity in collaborative human-computer problem solving'.

Carlsson and Walden in a number of papers (cf. [3, 4, 5, 21]) have shown that active DSS can be built with a hyper knowledge support technology (in which concepts interact) in which the supported decision maker can (i) build, explore, modify and use concepts to understand his problem context; (ii) link concepts to build models; (iii) use models interactively for descriptive problem understanding and analytically for effective problem solving; (iv) use data, information and knowledge to support the use of models, and (v) share his models and his understanding with others in order to improve the productivity and the effectiveness of (for instance) a management team. It has also been shown in a large number of cases that hyper knowledge support systems can be used in strategic management, and will then be independently used by senior management [4]. Finally, it has been shown that by enhancing the hyper knowledge technology with fuzzy logic [5] it will be possible to bring about the collaborative human-computer problem solving Anghern [1] has advocated.

In the following section we will use Keen's agenda for 'the next decade of DSS', but we will update it from 1987 to 1997, and look ahead to the year 2007. Much has happened to the technology available to us for building decision support systems, and as a consequence, much of how we perceive the use of a DSS has changed. The senior users we have met in the late 1980's (and in the 1990's) are different, and will be quite different from the senior users of the 2007. The compromises we have made with the system designs in order to facilitate the use of DSS by the inexperienced senior users of the late 1980's will not be necessary for the senior users of the 2007.

On the other hand, the new generation of senior users will be technologically much more advanced and will expect more of the functionality offered to them by DSS technology. Following Keen's agenda, we will identify a few areas, where DSS designer skills will both make sense and make a difference.

In the last few years we have seen a steady inflow of models and tools for multiple criteria decision making in DSS applications (Keen's second point), and it appears that this will continue as we get more advanced mathematical programming software integrated with (for instance) MS Excel.

The use of AI, as advocated in Keen's third point, is being replaced with intelligent systems and soft computing, which are emerging new technological platforms.

The special value of DSS practitioners is being assimilated in systems applications which are built with modern information technology (IT) - in a sense, the success of the DSS visions and methods has made the original DSS concept obsolete. We make this point further on but we introduce the active DSS concept to point the way to applications, which will make use of the new IT solutions. We will also show that active DSS can be construed as a new paradigm for a better understanding of decision making, problem solving and planning processes in environments which have not been accessible for systematic studies with traditional research instruments.

In Section 3 we will give a brief summary of hyper knowledge and a brief summary of some experiences we have gained by using the hyper knowledge principles as a basis for support systems in strategic management in several industries. In Section 4 we will give a quick summary and overview of new trends in IT and intelligent systems, and how these will influence the DSS technology to be used by senior managers in 2007.

We will also spend some time with a discussion of soft computing, which appears to become an important methodological basis for intelligent hybrid systems, which include fuzzy logic, artificial neural nets and self-organising maps, genetic algorithms and probabilistic modelling. In section 5 we consolidate the trends and new technologies with the key notions of decision support in order to build a platform for the material we are going to introduce in the following chapters.

Briefly stated, modern information technology, intelligent systems and soft computing will form a better basis (or even a new paradigm) for better decisions, more effective problem solving and more systematic planning. As we will try to show, this will help build better and more effective management - and probably better leadership.

3. Hyper Knowledge - a Brief Summary of Experiences

The first systematic discussion of hyper knowledge was published by Chang, Holsapple and Whinston [6] in 1993. They introduce the principle that a DSS should form a "hyper knowledge environment" with its users, i.e. the DSS should be an extension of the user's acquired knowledge management capabilities. In their own words (p. 19),

> "...we might conceive of an ideal DSS as a knowledge-rich environment in which a decision maker is immersed. In this environment, the decision-maker is allowed to contact and manipulate knowledge embodied in any of a wide range of interrelated concepts. The decision-maker is able to navigate spontaneously through the DSS's concepts in either a direct or associative fashion, pausing at a concept currently in focus to interact with it or an image of it. The type of interaction that is possible depends on the nature of the concept or its image. A decision support environment ideally is an extension of the user's private cognitive world, pushing back cognitive limits on knowledge representation. Its knowledge processing capabilities augment the user's mental skills, overcoming cognitive limits on the speed and capacity of strictly human knowledge processing."

This metaphor describes some useful characteristics of the hyper knowledge environment. They can be taken as more or less generic and independent of the means and modes of implementation: (i) the user can navigate through and work with diverse concepts; (ii) concepts can be different epistemologically, (iii) concepts can be organised in cognitive maps, (iv) the concepts can be made interrelated and interdependent, (v) relations can be structured or dynamic, and (vi) relations can change with or adapt to the context. There are also a couple of problems with a hyper knowledge environment: (vii) it has turned out to be too informal and unstructured for handling complex problems and (viii) users can easily get lost in a conceptually over-rich environment, i.e. they lose touch with the tasks they try to accomplish.

This is perhaps better understood when the decision maker is described through a cognitive metaphor: a decision process is built and carried to its conclusions by navigating through a universe of concepts. Some of these concepts are descriptive, some are procedural, and some are context dependent, others are abstract or goal formulating and some are used as motivating concepts, which serve as instruments to forge a joint value and goal system. The actual decision making is an appreciative process in the sense introduced by Vickers [20], i.e. concepts are evaluated against each others, their importance and influence are appreciated, and an emerging decision is continuously adapted and modified to the concepts.

The ideal DSS for this purpose is a knowledge-rich environment for the user, in which he can access and manipulate concepts and work out their interdependencies - as described by Chang et al [6]. We would want to build the DSS in such a way that the interdependencies represent the internal logic of the context the user tries to understand and tackle. If we manage to do this, then the decision process will progress towards decisions, which are overall optimal in the sense that they are construed as the best alternatives in terms of all elements of the universe of concepts.

One of the contexts in which a hyper knowledge DSS environment intuitively makes sense is *strategic management*, in which we always deal with a multitude of issues, which needs to be evaluated in systems of concepts - in various value systems - as we have groups of people concerned with the issues.

For this context we designed a support systems technology for strategy formation, which was called *Woodstrat*, as it was developed and implemented for strategic management in two major, Finnish forest industry corporations in 1992-94. The development work was done interactively with management teams and involved more than 60 managers in 14 strategic business units (SBUs). The total amount of resources used for developing the system was about 20 man-years [cf. 3, 4, 5, 21] for details. The approach we have used has been rather straightforward, as is demonstrated in Fig. 1.1.

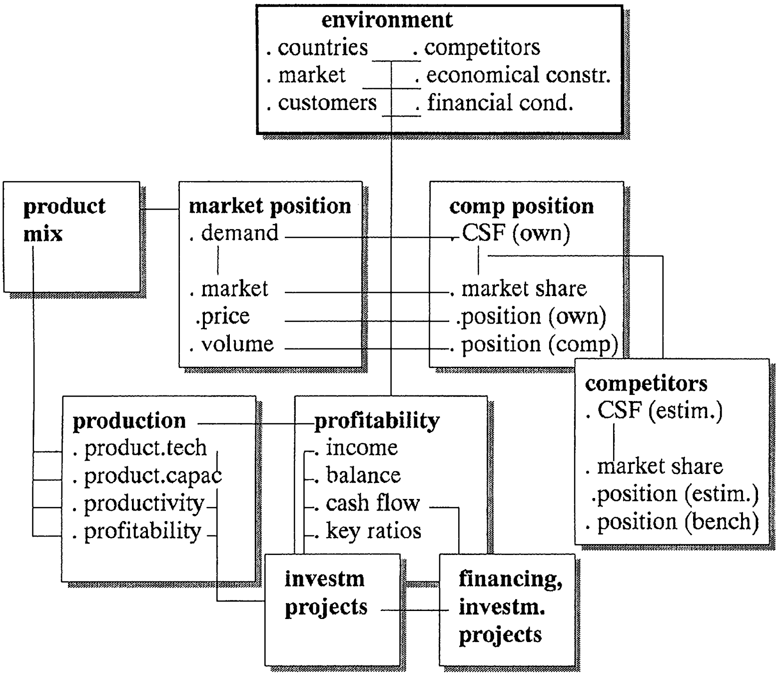


Figure 1.1. Hyper knowledge support environment for strategic management.

The hyper knowledge support environment (≈ *Woodstrat*) shown in Fig. 1.1 has most of the characteristics described in the Chang et al [6] paper:

- The environment is knowledge-rich for strategic management, as it supports planning and problem solving in terms of (i) the environment of operation; (ii) market position in terms of product mix, demand and prices; (iii) competitive positions, both for the company and for its competitors; (iv) production, in terms of production technology, capacity, productivity and profitability, and (v) profitability in terms of income, capital ('balance' in Fig. 1.1), cash flow and key ratios, and with investment projects and their financing incorporated with the assessment of profitability.
- The lines show interrelations among concepts forming the strategic management environment. The interrelations are functions, logical

connections, operators, agents, etc. and can be described as the following system of functions (cf. Fig. 1.1):

- Market position = f_1 (macroeconomics)
- Sales in segment = f_2 (demand in segment) & f_3 (market position in segment) & f_4 (competition)
- Demand in segment = f_5 (customers, potential customers in segment)
- Competition in segment = f_6 (players)
- Competitive position = f_7 (CSF, market position, competitors position)
- Critical Success Factors = f_8 (core competencies)
- Competitors position = f_9 (CSF)
- Production position = f_{10} (technology, product quality, used capacity)
- Technology = f_{11} (innovations, cost effectiveness)
- Product quality = f_{12} (technology, user value)
- Used capacity = f_{13} (demand, available capacity, investments)
- Profitability = f_{14} (sales, used capacity, cost effectiveness, RONA)
- RONA = f_{15} (capital used, investments)
- The user can start anywhere in the environment (e.g. in the market position) and formulate his visions or his goals on this position,

  and can then work out the consequences on all the other positions through the links.
- The cognitive worlds of the user get implemented in the environment through initial assumptions and proposals, through continuous, interactive use and through continuous updates from many (external, internal) data sources.
- The user's mental skills are continuously augmented as tens of interrelated activities are triggered with new goals or decisions on any activity, or with key events which are described by data sources, and are subsequently worked out through the network of links.

After the *Woodstrat* the technology has both been expanded to new sectors of the forest products and forest machinery industry, and adapted to and implemented also in the telecommunications, the insurance and the plastic pipes industries in 1995-96. The hyper knowledge platform was rewritten in 1997-98 to include some new intelligent systems technology and was then applied in the alcoholic beverage industry. At present a new generation of hyper knowledge technology is being developed, which includes software agents, smart user interfaces, secure web-communication, soft computing models and multiple criteria optimization tools; this work is carried out as part of two major, international research programs.

In terms of technology, the *Woodstrat* was already a hybrid system. The prototype versions were first built in Lisp and Toolbook, later versions were done with Visual Basic and included a number of specially designed software modules to implement the hyper knowledge features.

One of the implemented versions of the support system was done with Delphi and MS SQL 6.5 as the development environments. It became apparent after a while that the support system we get in this way is both too complex for senior managers to use, and that the adaptation of the system to changing environments became too cumbersome. These problems were mostly due to the MS SQL. It also turned out that the design was too time consuming to build for fast prototyping.

We then found out (by some fast search-learning processes) that the object-oriented programming approach we were using could be transformed to a much lighter framework by using Java-based functions and modules, and by replacing the relational databases favoured by the Delphi with data warehouses.

The user interface was designed as a user-friendly platform (which resembles the point-casting platform, a very effective and user-productive interface) for senior managers, which is supported with a data warehouse built in Oracle 8.0 and with Java-implemented links to external data sources. The use of external data supports the follow up and continuous assessment of the macroeconomic environment, key industrial changes and developments, competitors and their activities and significant changes in key market characteristics. The use of external data sources is supported with software agents.

The hyper knowledge support system is a client-server solution in Windows and we have fully exploited the functionality offered by this environment. The system is compact, fast and very effective in terms of computer resources. It can be run on LAN-connected office workstations, on stand-alone portable PCs and (in the latest version) over Internet, which allows the users to use the support system wherever they need to access it, in or out of office [4].

There are still some unresolved problems both with developing support systems for strategic management and with the conceptual richness of hyper knowledge. We are looking for ways to develop the hyper knowledge environment to combine quantitative with qualitative assessments in analysis models. We want to combine empirical hard facts with knowledge-based estimates and proposals in order to find a synthesis and new knowledge. We would like to combine interactive and (more or less) intuitive problem solving methods, building on learning processes, with numerical optimization methods, which would be helpful for tackling complex problems, in which part of the complexity is due to imprecise and incomplete information and knowledge.

In recent years there has also been some advance in modern modelling technology, which allows the use of approximate reasoning with incomplete and spotty data, and fast, on-line optimization from data in spreadsheet format. The use of artificial neural nets (ANN), fuzzy filtering and fuzzy logic, genetic algorithms, simulation, animation, etc. are becoming more and more standard for modelling complex phenomena, as the software to enable this modelling is becoming available as Windows applications.

4. New Information Technology, Intelligent Systems and Soft Computing

Marakaz [15] has collected material from several sources and describes the future of support systems technology and its role for executive decision making. Several of his insights will be highlighted in the following.

As we pointed out in the introduction, we are getting larger groups of senior executives, who are comfortable with IT and who have hands-on experience with the use of computers. The former roadblocks of the 1980's and 1990's for the use of IT in executive decision making are being removed as the realisation has grown that IT is both useful and valuable to the organisation.

Modern corporations and their strategic business units will continue to loose their hierarchical organisation structures. The stated objective is to create business entities, which are leaner, more flexible and more responsive to a rapidly changing business environment. This has been implemented as reductions in staff and middle management personnel and senior managers and executives get involved much more directly with problem solving, decision making and planning than they used to be in the 1980's.

The boundaries of business entities will continue to expand and blur. Markets are global in most advanced products and services (which most business entities would want to work with) and the competition for market share, customers, resources and skilled personnel will continue to escalate. At the same time the social infrastructure and the impact of

(EU-driven) public sector regulations will become more and more complex. The increasing complexity of the context for planning and carrying out business operations underlines the need for support systems driven by advanced and modern IT. It is a truism that the data, information and knowledge that should be mastered by the fewer senior people, who man the responsible positions in the leaner organisations, will continue to grow and become more complex. As the dynamics of the global markets increases the need for accurate, more diverse and immediate information will continue to grow. This supports the need for a continued effective use of modern IT in support of planning, problem solving, decision making, operations and management.

It was, of course, only a matter of time but Watson, Houdeshel and Rainer (1997) [22] proposed that the EIS of the future should become an *executive intelligence system* (even if this may produce unfortunate suggestions about the capabilities of senior decision-makers).

The first target for some sort of intelligent systems technology should be the overwhelming flow of data, information and knowledge produced for the executives by an increasing number of sources. The EIS should have facilities for screening, sifting and filtering the flow.

In the 1980's a number of studies proposed that expert systems should be integrated into the executive information systems, which at that time were marketed to supply the executives with 'all and relevant information they need'. The task of the ES modules were to propose models to be used for data analysis and problem solving, to help trace and pick up data from systems of databases and to support senior users, many of whom were uncomfortable with computer-based support systems. These ideas never gained any significant support even if the Comshare products sold quite well for a while.

The ES technology is now being replaced by intelligent systems, which are built to fulfil two key functions. First, (i) the screening, sifting and filtering of a growing overflow of data, information and knowledge (described above), and second, (ii) the support of an effective and productive use of the EIS, which quite often is tailored to the needs and the personality of the user. The intelligent systems, which can be implemented for these purposes, range from self-organising maps to smart add-on modules to make the use of standard software more effective and productive for the users.

A new component being proposed for the EIS is a multimedia database management system, which should allow a user to work with text, voice and images (drawings, pictures, and video) in an integrated database structure. The user interfaces remain so complex and the notion of combining these database elements professionally so demanding, that the multimedia database applications will remain the domain of skilled professionals for still some years.

Software agents (also called intelligent agents) have been designed and implemented to take care of the screening, sifting and filtering of a growing overflow of data, information and knowledge. The Java-built components can be designed and implemented to search for data sources with user-defined search profiles, to identify and access relevant data, to copy the data, and to organise and store it in a data warehouse [13]. Other agents of the same "family" can then be used to retrieve the data, insert it in reports and to distribute it via e-mail according to topic-specific distribution profiles.

The software agents can be designed to combine with smart add-on modules to provide users with relevant data in a way, which reduces the time spent on the routines to a fragment of the time otherwise needed to search for, copy and combine, report and distribute the data.

As a final point of discussion on the future support environment for senior managers and executives, let us take a look at the virtual reality (VR) technology. From time to time writers have proposed the building of executive "war rooms" in which different scenarios of future developments could be simulated and tested in a gaming-like setting. The present VR technology is more focused on individual experiences as one of the definition states that VR is "an environment and/or technology that provides artificially generated sensory cues sufficient to engender in the user some willing suspension of disbelief"(cf. [19]). This suggests that in virtual reality a person will interact with his environment as if it were real, although it is artificially created with computer software and multimedia technology.

There has been some success with VR as a planning and presentation tool (cf. [15]) and this seems to be the arena, where we will see more of VR as a support tool in the future. Another area for VR applications is data visualisation - some decision-makers have difficulties to understand data displayed in spreadsheets or 2-dimensional graphs as they do not see the underlying relationships, but will quickly grasp them from 3-dimensional animated displays. This may be one of the areas in which we will see much more of VR technology in the years to come, if the cost-benefit ratios of the technology become reasonable.

4.1 Intelligent Software Agents

There is a new type of intelligent systems, which are called software or intelligent agents. Following [14] we will adopt the name *intelligent software agents* (ISA) in order to capture the notion of both intelligent features and the implementation with computer software.

Writers agree (cf. [15], [19] and their references) that ISA's will probably be among the most important advancements of the DSS environment in the first decade of the 21st century. The roles of ISA's in a decision support context will show both a wide scope and a variety of tasks, but a typical mission profile would include the following four areas of activities.

The ISA's could work as *information customizers*, which would follow hundreds (or even thousands) of data sources both on the intranet, extranets and the Internet, and collect pre-specified data, screen and filter it, and then sort it into categories for efficient handling.

The ISA's are designed to work as monitors of weak signals looking for events in thousands of data sources with the help of webs of keywords, which also can be adapted and developed through learning processes.

The ISA's can be used as help desks, for which they would take the basic parameters (submitted by an employee or a customer) of a problem and use them to retrieve relevant technical information from a database. This will save the time of the systems users to look for and retrieve the information or to write database queries to get the information. The ISA's can, finally, be used for *data mining* when enhanced with tools for pattern recognition such as self-organizing maps, neural nets, approximate reasoning schemes, etc.

Maes et al [14] show that software agents are moving into e-commerce to work as facilitators for conducting transactions - business-to-business, business-to-consumer and consumer-to-consumer - through Internet - and web-based channels. The agent technology can be and is used to automate several of the most time-consuming stages of the buying process: personalized, continuously active and semi-autonomous agents can optimize the buying experience, they can serve as mediators and they can support negotiations among commercial partners.

There is already some controversy on what an ISA is and what properties computer software should have in order to be classified as an ISA. This is only to be expected, as the ISA will become commercially very interesting.

There are two common features in most definitions (cf. [15]): (i) an agent is one who acts, or who can act, and (ii) an agent is one who acts in place of another person with permission from that person. Franklin and Graesser [8] offer a formal definition of ISA's:

> An autonomous agent is a system situated within and a part of an environment that senses that environment and acts on it, over time, in pursuit of its own agenda and so as to effect what it senses in the future.

This broad and general definition encompasses a number of more specific definitions, often related to commercial applications. In the following, we will work through a few of these definitions in order to get some substance on the ISA's (cf. [15], in which a number of definitions have been summarized):

> Intelligent agents continuously perform three functions: perception of dynamic conditions in the environment; action to affect conditions in the environment; and reasoning to interpret perceptions, solve problems, draw inferences, and determine actions. [Hayes-Roth Agent].
>
> Intelligent agents are software entities that carry out some set of operations on behalf of a user or another program with some degree of independence or autonomy, and, in doing so, employ some knowledge or representation of the user's goals or desires. [IBM Agent].
>
> A hardware or (more usually) software-based computer system that enjoys the following properties: (i) autonomy. Agents operate without the direct intervention of humans or others and have some kind of control over their actions and internal state. (ii) social ability. Agents interact with other agents (and possibly humans) via some kind of agent communication language. (iii) reactivity. Agents perceive their environment, which may be the physical world, a user via a graphical user interface, a collection of other agents, the Internet, or perhaps all of these combined, and respond in a timely fashion to changes that occur in it. (iv) proactive-ness. Agents do not simply act in response to their environment; they are able to exhibit goal-directed behaviour by taking the initiative. [Wooldrige-Jennings Agent].

These definitions point to a number of features software should have in order to work as ISA's (cf. [15], where a number of features have been collected from various sources).

The first feature is that they should be *autonomous*; they should have the capability to carry out spontaneous execution and pre-emptive or independent action, which will carry out the objectives of the user. These actions should be context-dependent and context adaptive. In this sense an ISA differs from standard software applications, which respond only to direct input and work independently of the context. Finally, an ISA should be continuously operational, even if the user is inactive, in order to be autonomous.

The second feature is that an ISA should be *adaptive and tailored* to the objectives and needs of its user, so that its capabilities can be changed with changing users and changing contexts. A learning ISA can accomplish this by monitoring both its environment and the initial actions of its user.

The third feature is the capability of *discourse and cooperation* with the user(s), which will make sure that the intentions with using the ISA, and properly calibrating it, can be tested and validated. This feature is also a requirement for cooperation with other ISA's, as some task may require that ISA's with special features work together in order to properly use available data sources.

The fourth feature is the notion of *delegation*, which means that the ISA is given the responsibility of carrying out context-specific tasks the user(s) could carry out, but have decided not to spend time and resources on. The delegation of tasks is a compromise between accepting the risk that the ISA would not work properly and the economics of using scarce resources more effectively for other tasks. This requires that the ISA designer is familiar with the domain in which the ISA is going to operate and that the context-specific design of its capabilities is tested and validated before it is launched.

The fifth ISA specific feature is the capability of gradual *degradation*, which means that the ISA will not fail completely but carry out parts of its assignment. This will happen if its capabilities do not match the tasks given it, or that the context turns out to be dynamic and changing at a rate the ISA cannot keep up with. By this gradual degradation it is possible to trace its progress and learn how the ISA should be designed - and it is always better to get part of the task accomplished than to fail completely.

The sixth feature is called *anthropomorphism*, which is used to make an ISA believable as it can be seen and heard, and because it has some identifiable (and likable) features. It is believed that this will make interaction with a user easier and more pleasurable. The MS Office Assistant is an ISA with personal and likable characteristics, which will help an irritated user to accept guidance when things have gone wrong in an Office application.

The seventh and final feature mentioned is *mobility.* An ISA, which is mobile, can move from a server, or a workstation, to another using an intranet or the Internet. The reason for having them to move is that they get closer to data sources and can process the data locally. A moving ISA can be built to choose when and where to migrate, it can start executing a program on one client-server group, migrate to another client-server group and then resume the execution on this. The mobile ISA has several advantages as compared to a fixed client-server architecture: (i) mobile ISA's use fewer network resources as they move computation to the data rather than data to the computation resources; (ii) mobile ISA's do not require a continuous connection between client-server groups; (iii) mobile ISA's hide the communication channels but not the location of the computation; (iv) mobile ISA's allow client-server groups to extend each other's functionality by programming each other.

These features have been used to build taxonomies and classifications of ISA's, which seem to be coming along quite early and rather faster than real-world applications of ISA's. Brustoloni [2] developed one of the first taxonomies of ISA's:

Regulation Agent: Reacts to each sensory input as it comes in and always knows what to do. This agent neither plans nor learns.

Planning Agent: Performs planning functions using case-based or randomizing algorithms. This agent cannot learn.

Adaptive Agent: The agents can learn while simultaneously performing planning.

These categories are, of course, broad and descriptive, but they give an idea what type of constructs ISA's could be. Lee, Cheung and Kao [12] give another taxonomy based on the level of intelligence built into the ISA's:

Level 0: Agents retrieve documents for a user under straight orders. The user must specify the exact location of the desired documents (cf. a typical web browser).

Level 1: Agents conduct a user-initiated search activity. Agents can match user-supplied keywords with indexed information (cf. Internet search engines such as Yahoo, Alta Vista, etc.)

Level 2: Agents maintain profiles on behalf of their users. Agents can monitor various information sources and notify the user whenever relevant information is located or new information is discovered (cf. WebWatcher).

Level 3: Agents learn and deduce from user-specified profiles to assist in the formalisation of a query or target search (cf. DiffAgent).

The challenges in work with ISA designs are on the intelligence level 3, on which the most productivity is to be gained from the deployment of ISA's in support of the users.

The DSS user is a limiting factor on the productivity of DSS applications, as his/her cognitive ability cannot keep up with the data processing capacity of modern IT. Here the ISA's will become useful tools as they can be used as background operations to screen data sources, to collect, sift and filter data, and to organise it into useful categories for DSS applications (which often includes organising numerical data into a spreadsheet format for Excel applications).

Many information systems users have gradually learned how to master a client-server environment and are reasonably productive when working with Windows-based software. The next step promises to be network computing, in which non-professional users are expected to be productive in a much more complex environment in which both data and applications are spread all around. Here the ISA's will be needed both as help desks and as means for providing a productive and effective infrastructure for network computing.

The ISA-enabled applications are emerging as viable business applications. The Lotus Notes environment is strongly ISA-enabled and the fast growing electronic commerce environments are going to require new generations of more intelligent ISA's with a growing number of multiple purpose functions to support decidedly non-professional users.

4.2 Soft Computing

Soft computing includes research on fuzzy logic, artificial neural nets (ANN), genetic algorithms (GA) and probabilistic modelling. The added feature to the intelligent systems we have just discussed is that soft computing machine learning systems (for instance) are developed using fuzzy logic and the fuzzy sets theory as a theoretical and methodological basis.

This can easily be seen from the fact that both ANN and fuzzy logic can be used to approximate non-linear relationships among variables in order to deal with complex systems. An ANN makes sense when we have access to lots of data. We can use the data to train an ANN until it generates the non-linear relationships, which fit the data. Fuzzy logic applies to the opposite case: we do not have lots of data, but we have access to experts who can describe part of the complex system's behaviour in terms of rules, which are generally accepted (or acceptable) as non-refutable. If the experts can provide us with precise rules, i.e. rules, which are precise enough to be usable in an intelligent system, we will use them and build a crisp reasoning system. If the experts cannot be that precise, which the case is most often, we use fuzzy rules and build an approximate reasoning system. In general, the approximate reasoning system is more stable and more useful for all practical purposes.

Work has also been done to combine the ANN with fuzzy logic, which has resulted in the *neural fuzzy systems* (cf. Fullér [9]). In this approach we would have a reasonable amount of data available, which could be used to determine the parameters defining the membership functions used in approximate reasoning schemes. Then we get the best of both technologies: the ANN gives a sufficiently good data basis for reasonably precise estimates of the membership functions, and the fuzzy logic of approximate reasoning gives a stable, general and powerful intelligent system.

Fuzzy sets were introduced by Zadeh as a means of representing and working with data that was neither precise nor complete, but vague and incomplete. Fuzzy logic provides an inference morphology, which enables the principles of approximate human reasoning capabilities to be systematically used as a basis for knowledge-based systems.

The theory of fuzzy logic provides a good mathematical and methodological basis for capturing the uncertainties associated with human cognitive processes, such as identifying causal relationships, thinking and reasoning. The conventional approaches to knowledge representation lack the means for representing the meaning of vague and incompletely understood concepts. As a consequence, the approaches based on first order logic and classical probability theory do not provide appropriate conceptual frameworks for dealing with the complexities of real world problems and common sense knowledge, since such knowledge is by its nature lexically imprecise, non-categorical and incomplete.

The problems outlined with the standard, conventional representations of knowledge are well known for everybody working with support systems, both when designing and building the systems, and when trying to implement them and to make them work for real world applications. When used to deal with the complexities of real world applications - especially when they are designed to deal with management problems - systems constructs have become large and complex, quite hard to understand and build, and even harder to use and support. Clearly, there is a need for alternative approaches, and knowledge based systems built with fuzzy logic have started to appear as viable alternatives.

The development of fuzzy logic was motivated - to a large extent - by the need for a conceptual framework which can address the issues of uncertainty, lexical imprecision and incompleteness. Some of the important characteristics of fuzzy logic include:

- exact reasoning is viewed as a limiting case of approximate reasoning;
- knowledge is interpreted as a collection of elastic or fuzzy constraints on a collection of variables;
- inference is viewed as a process of propagation of elastic constraints;
- any logical system has a fuzzy logic based counterpart;

There are two main characteristics of fuzzy systems that give them better performance for specific applications: (i) fuzzy systems are suitable for uncertain or approximate reasoning, especially when the systems are difficult to describe with a mathematical model; (ii) fuzzy logic allows problem solving and decision making with estimated values on the basis of incomplete or uncertain information.

The successful uses of fuzzy logic in control applications in the last 10-15 years has motivated and initiated work on expanding the use of fuzzy logic in information systems, and also in decision analysis and data mining (cf. [23, 24, 25, 26]).

Let's take a closer look at *fuzzy logic*, which is at the core of soft computing. Lotfi Zadeh gives a neat summary of the reasons for moving away from the standard intelligent systems technologies when we have to deal with the complexity of a dynamic business world:

As complexity rises, precise statements lose meaning and meaningful statements lose precision.

Fuzzy logic is a method of approximate reasoning (AR), which allows for partial or fuzzy descriptions of rules. The reasons for using fuzzy logic comes from the possibility to describe a complex process linguistically, i.e. in concepts and terms which are intuitively understandable, and then to represent that description in a small number of very flexible rules. The knowledge in an approximate reasoning system is carried both in its rules and in its descriptive fuzzy sets, which give us general descriptions of the properties of the process and the events, the phenomena and the objects going into it.

Dahr and Stein [7] state one of the truisms in approximate reasoning: fuzzy logic does not mean that we are satisfied with or aim at getting vague answers. The reasoning process is built in terms of approximations in order to make use of imprecise knowledge, but with precisely stated (numerical) inputs we can build the process to produce precise, numerical outputs.

Let's focus on three, typical strategic management problems in which it would make sense to work with fuzzy logic.

A forest product corporation would like to build a system to monitor investment opportunities in its logistics and market supply chain, as it happens that a good way to create sustainable competitive positions in customer markets is to control the distribution channels to profitable and growing customer segments. The business environment for the logistics and supply chain is highly dynamic, the players merge and split and the customers change their preferences. Much of the data is secret and sensitive, and not willingly shared with the forest products companies. Thus, the context is complex and difficult to master. There are a number of specialists around, who know the logistics arena and would be able to describe it in rules, which would be generally accepted (or acceptable) as non-refutable.

In strategic planning support systems we normally have integrated large databases, which cover markets, customers, products and competitors. For building strategic plans we are less interested in detailed and precise data (which we can retrieve with SQL queries, if we know how to build an SQL query) than in being able to work with imprecise categories. We would, for instance, like to know 'customer segments which would prefer slightly higher quality fine paper products from StoraEnso at moderately higher prices, if the deliveries are more prompt than the deliveries of our high quality products'.

The marketing division of a Finnish forest product corporation has a large database of customer market information, and would like to find out if their customers make good enough forecasts of the varying demand patterns of their own customers. Knowing this would be helpful in predicting how much each customer will be ordering in the next quarter. The marketing division employ some seasoned and highly skilled market analysts, and it will be possible to both capture the tacit market knowledge they have, and to describe it with a series of approximate reasoning rules.

Issues of this type cannot be dealt with effectively with any of the standard intelligent systems technologies, but fuzzy logic will work and there are several reasons for this.

Fuzzy logic is axiomatic and there is a complete framework of carefully designed and derived logical rules to build up this framework. This creates conceptual rigor and precision. On the other hand, the fuzzy sets describing the context to be handled are context sensitive, which allows us to be both precise enough and relevant for the specific issue to be handled. If the descriptions are generic, i.e. they are built to cover all possible situations, they have to be either precise (and will lose in relevance) or general enough to be relevant in all situations (and will lose in precision). This is not the case with fuzzy sets.

When we use sets of rules to represent expert knowledge for a standard expert systems application, we will have to work with crisp categories. Otherwise the system will not work. Consider the following rule[3] (cf. [7]):

If years-of-employment is LONG,
then credit-risk is LOW

When we work with crisp categories we need to define LONG; let it be 8 years. If Ville has been working for 7 years, 11 months and 19 days his application for a loan is rejected; if Kalle has been working for 7 years, 11 months and 21 days his corresponding application for a loan will be accepted due to banking rules. This is unfair to Ville, and for all practical purposes the bank will grant him a loan. If we use an intelligent system to work through loan applications, Ville will again be rejected. The problem is with the crisp categories, which do not take into account the context.

With fuzzy categories we will be better off. The *years-of-employment* would be classified in three categories SHORT, MEDIUM and LONG, which are made to overlap. Belonging to a category is judged with a membership grade in the interval $[0, 1]$. If Kalle gets a grade of 1.0 for his *years-of-employment* in the category LONG, Ville is sure to get a grade over 0.95 (and a grade of 1.0 in MEDIUM, and a grade of 0.05 in SHORT).

This will depend on the form of the membership function, which (as it is context-sensitive) can be built to more or less ignore differences of a few days if the qualifying period is as long as 8 years. Through the axioms for the AR-schemes there were introduced maxmax- and minmax

[3]Here we will briefly work through some examples with fuzzy logic without using any formalism in order to show some of the features. Proper definitions and forms will be introduced later.

rules, which link the categories LONG and LOW (for the *credit-risk*). Through these rules we can find that the grade of membership for Ville in the category (*credit-risk* is LOW) would be 0.95, and Ville would be approved for a loan if the grade for getting a loan is, for instance, ≥ 0.80. The significant thing is that the AR rules are context sensitive in the sense that they build on experience, subjective judgement and common sense.

If there is a precise, numerical input to an AR scheme there are methods available to get a precise numerical result. One method works out the centre of gravity in the overlapping categories (and is thus called the centroid or gravity method) and determines a precise, numerical grade of joint membership.

The AR rules are effective as they allow us to state relationships very generally and very compactly as associations. There is the added benefit of avoiding undue artificial precision, as we can use the precision required by the context and merited by the data - or dictated by the common sense of the decision-makers.

The AR-scheme allows us to deal with complexity (Zadeh: *As complexity rises, precise statements lose meaning and meaningful statements lose precision.*). We get complexity if we try to cover all the interdependencies of (for instance) the price-forming mechanism in a fine papers market. We know that key determinants are: the expected movements and levels of pulp prices, inventory levels in the paper markets supply chain, the expected GDP changes in the paper market countries, interest rates, currency rates, energy prices, etc. The interactions among these factors are highly dynamic and nonlinear, and all attempts to build effective predictive tools (using econometric modelling, system dynamics, etc.) have failed.

With standard mathematical tools we need large sets of high quality, precise and complete data to get the parameter estimates we need for the models. For practical purposes we cannot normally get this data - with reasonable cost and within reasonable time. Then the AR schemes offer an attractive trade-off between accuracy, completeness and scalability. With the AR scheme we can get reasonably good predictions and estimates, even if the data is imprecise or poor and we do not have much time or resources for data collection.

Another feature of the AR-schemes is that they become very compact. If we want to cover possible variations of pulp prices for the next 12 months we will need a dozen to two dozen rules if we want to work with precise predictions. Working with fuzzy rules it will be enough to have 3-5 rules covering the categories (LOW - (MEDIUM LOW) - MEDIUM - (MEDIUM HIGH) - HIGH). We can further break down these rules into local rule sets (around MEDIUM LOW, for instance) and still work with very few rules as we increase the precision.

This is actually a good example of the information granulation concept recently introduced by Zadeh in 1997 [27]. Granulation involves decomposition of the whole into parts, and is one of the three basic concepts underlying human cognition. The counterpart of granulation is organisation - the integration of parts into a whole; the third concept is causation, which involves association of causes with effects. The theory of fuzzy information granulation is built on the human cognitive ability to granulate information and to reason with it, but the foundation and the methodology are mathematical (which is similar to fuzzy logic and fuzzy sets). The intentions behind the new theory is to provide a foundation for the further evolution of fuzzy logic, to give a conceptual basis for the computing with words modelling and to advance the growth of hybrid intelligent system, which will combine fuzzy logic, ANN, GA and probabilistic modelling.

Let us then, in the next section, revisit Keen's agenda for the future of DSS.

5. Some Lessons for Future DSS

In the *Woodstrat* project [3, 4, 5, 21] the context was strategic management, which is a relevant context for senior managers, and the support was tailor-made to the logic of the strategic planning process. It turned out that the DSS actually became a tool for the senior managers involved.

If we want to keep up with some of the earlier visions - the DSS as a support system for all levels of management [18] - we could broaden the scope for the future DSS to include relevance for a variety of contexts and users. We should, however, still aim for systems, which are meaningful, relevant and productive for the users.

The DSS technology has been around in various shapes for almost 30 years but, as Keen [10] points out, there is no generally accepted definition of the DSS. Moreover, there should not be any as a DSS is always a context-dependent construct which is designed to serve an individual or a group of decision makers, and to provide the best possible support in a variety of planning, decision making and problem handling situations. Keen emphasises that we should focus on the kind of *support* we plan to offer the DSS users, as the technological platforms will change over time and any definition linked to technical aspects very quickly will become obsolete.

Keen also expected the development to exploit new software tools and AI, and to be far more prescriptive on how decisions should be made more effectively. The standard DSS approach mostly [17, 18] gives a good description of ill-structured problems as a basis for some analytical efforts at solving them. With the hyper knowledge environment we can accept a further challenge - to provide a knowledge base for dealing with ill-structured problems.

Anghern [1] makes a distinction between *active* and *passive* support with computer-based support systems. In a "palette of possibilities to provide support" he distinguishes between "vehicle" and "tool-book" DSS. The former category represents DSS which propose/impose a specific methodology on the user - they give guidance at the cost of flexibility. The latter category of DSS is flexible in enabling their users to exploit different approaches and tools, but they provide little guidance on problem representation and exploration. Anghern developed a conversational framework for decision support - which is a teamwork environment - in order to recreate a natural setting in which problems can be exposed, discussed and explored.

Here we have explored a number of possible, alternative environments in which we have used a hyper knowledge platform, and enhancements and extensions to it with intelligent systems and soft computing. The resulting platform will probably be significantly more powerful than the conversational framework Anghern had in mind.

An active DSS is probably a decision support technology, which is flexible to the needs of the users and the visions and requirements of a changing environment. In the *Woodstrat* project the DSS was built as a series of interactive prototypes, with the actual and eventual users being part of the design process from the beginning. In this way we were able to get even senior managers to become active systems users, as they found out that they could express the internal logic of a strategic context in the way they had perceived it.

A hyper knowledge decision support platform should allow for quick and flexible prototyping, which makes it possible for the users to immediately test their intuitive understanding of the systems constructs. This can be enhanced to form an environment for interactive group-work on problem solving, planning and decision making.

With the help of the intelligent systems and soft computing technologies the DSS can be built in a way that significantly enhances the productivity of the user. The availability of proper modelling tools, effective methods for analysis and synthesis, and user-supportive tools for communication, data access and data handling, simulation, graphics and professional reporting will all contribute to productivity of working time - one of the goals of effective management.

Summarising all these insights the following outline of an emergent paradigm for future DSS becomes visible:

- decision support should be meaningful, relevant and productive for the intended future DSS users; these users could be both senior managers and managers from all levels of organisation;
- a DSS technology should allow users to share insights and combine problem solving skills, both same place - same time, different place - same time and different place - different time;
- a modern DSS should offer a platform for interactive group-work on problem solving, planning and decision making;
- the software platform for the future DSS should be chosen and/or developed to offer productive and effective support for the actual users: proper modelling tools, effective methods for analysis and synthesis, and user-supportive tools for communication, data access and data handling, simulation, graphics and professional reporting;

It is a truism in the field that the key problems never appear to be technology related, but they are "people problems": (i) people have cognitive constraints in adopting intelligent systems, (ii) people do not really understand the support they get and disregard it in favour of past experience and visions, (iii) people cannot really handle large amounts of information and knowledge, (iv) people are frustrated by theories they do not really understand, and (v) people believe they get more support by talking to other people (even if their knowledge is limited).

Nevertheless, it is becoming more and more apparent that (i) advancements in information, communication and computation technologies (ICCT) will produce more decision alternatives to choose from; (ii) increasing competition and a growing structural complexity in industrial sectors will contribute to larger costs of making errors; (iii) increasing changes in international markets, a decreasing political stability overall, increasing consumerism and increasing government interventions will produce more uncertainty about the future, and (iv) increasing changes and fluctuations will require quick decision making.

These arguments are today (as in the late 1970'es) supporting the use of decision support technologies for better decision making, even if the focus and the actual technologies used have evolved and changed with changing generations of information technologies.

As we will show in this book we will be much better off in this endeavour if fuzzy logic is used to enhance the technology with methods which can work with vague, imprecise and spotty data, information and knowledge.

References

[1] Anghern, A. A., Stimulus Agents: An Alternative Framework for Computer-Aided Decision Making, DSS-92 Transactions, TIMS College on Information Systems, Providence 1992, pp. 81-92.

[2] Brustoloni, J.C., Autonomous Agents: Characterisations and requirements, Carnegie-Mellon Technical Report CMU-CS-91-204, 1991.

[3] Carlsson, C., Knowledge Formation in Strategic Management, Proceedings of the HICSS-27 Conference, 1994, pp. 221-240.

[4] Carlsson, C. and P. Walden, Cognitive Maps and a Hyperknowledge Support System in Strategic Management, Group Decision and Negotiation, vol 6, 1996, 7-36

[5] Carlsson, C. and P. Walden, On Fuzzy Hyperknowledge Support Systems, NGIT'95 Proceedings, Tel Aviv, 1995.

[6] Chang, A-M., C. W. Holsapple and A. B. Whinston, Model Management Issues and Directions, Decision Support Systems, Vol. 9 1993, pp.19-37.

[7] Dhar, V. and R. Stern, Intelligent Decision Support Systems. The Science of Knowledge Work. Prentice-Hall, Upper Saddle River, 1997.

[8] Franklin, S. and A. Graesser, Is It an Agent or just a Program? A Taxonomy for Autonomous Agents, proceedings of the Third International Workshop on Agent Theories, Architectures and Languages, Springer-Verlag, Heidelberg, 1996.

[9] Fullér, R., Neural Fuzzy Systems, Åbo Akademi University Press, Åbo, 1995.

[10] Keen, P. G. W. , Decision Support Systems: The Next Decade, Decision Support Systems 3, 1987, pp. 253-265.

[11] Kohonen, T., Self-Organizing Maps, Springer-Verlag, Heidelberg, 1997.

[12] Lee, J.K.W., D.W. Cheung and B. Kao, Intelligent Agents for Matching Information providers and Consumers of the World Wide Web, HICSS-97 Proceedings, IEEE Computer Society Press, Los Alamitos, 1997.

[13] Liu, S., Data Warehousing Agent: In Seeking of Improved Support for Environmental Scanning and Strategic Management, Proceedings of the 6th European Conference on Information Systems, 1998

[14] Maes, P., R.H. Guttman and A.G. Moukas, Agents that Buy and Sell, Communications of the ACM, Vol. 42, No. 3, March 1999, pp 81-91.

[15] Marakaz, G. M., Decision Support Systems in the 21st Century, Prentice-Hall, Upper Saddle River, 1999.

[16] Mintzberg, H, The Rise and Fall of Strategic Planning, Prentice-Hall, Englewood Cliffs, 1994.

[17] Sprague, R. H. and Watson, H. J, Decision Support Systems: Putting Theory into Practice, Prentice-Hall, Englewood Cliffs, 1986.

[18] Turban, E. and J.E. Aronson, Decision Support Systems and Intelligent Systems, Prentice Hall, Sixth Edition, Englewood Cliffs, 2001.

[19] Turban, E., E. McLean and J. Wetherbe, Information Technology for Management. Making Connections for Strategic Advantage, J. Wiley, New York, 1999.

[20] Vickers, G.,The Art of Judgement, Chapman and Hall, London, 1965.

[21] Walden, P. and C. Carlsson, Strategic Management with a Hyperknowledge Support System, Proceedings of the HICSS-27 Conference, 1994, pp. 241-250.

[22] Watson, H.J., G.Houdesdal and R.K.Rainer, Jr, Building Executive Information Systems and Other Decision Support Applications, J Wiley, New York, 1997.

[23] Zadeh, L.A., Outline of a New Approach to the Analysis of Complex Systems and Decision Processes, IEEE Transactions on Systems, Man and Cybernetics, SMC-3 1973.

[24] Zadeh, L.A., The Role of Fuzzy Logic in the Management of Uncertainty in Expert Systems, Fuzzy Sets and Systems, Vol. 11, 1983, pp. 199-227.

[25] Zadeh, L. A., A Fuzzy Logic, IEEE Computer, April, 1988, pp. 83-93.

[26] Zadeh, L.A., Knowledge Representation in Fuzzy Logic; in: Yager and Zadeh (eds.): An Introduction to Fuzzy Logic Applications in Intelligent Systems, Kluwer Academic Publ, Boston, 1992.

[27] Zadeh, L.A., Towards a Theory of Fuzzy Information Granulation and its Centrality in Human Reasoning and Fuzzy Logic, Fuzzy Sets and Systems, 90, 1997, 111-127.

[28] Zeleny, M., Multiple Criteria Decision Making, McGraw-Hill, New York, 1982.

[29] The Kepner-Tregoe Survey on Speed and Quality in Decision Making, Research Monograph 2, June 2000; down-loaded from `www.kepner-tregoe.com`.

Chapter 2

FUZZY SETS AND FUZZY LOGIC

1. Fuzzy Sets

Fuzzy sets were introduced by Zadeh [9] in 1965 to represent/manipulate data and information possessing nonstatistical uncertainties. Fuzzy sets serve as a means of representing and manipulating data that are not precise, but rather fuzzy.

In classical set theory, a subset A of a set X can be defined by its characteristic function χ_A as a mapping from the elements of X to the elements of the set $\{0, 1\}$,

$$\chi_A\colon X \to \{0, 1\}.$$

This mapping may be represented as a set of ordered pairs, with exactly one ordered pair present for each element of X. The first element of the ordered pair is an element of the set X, and the second element is an element of the set $\{0, 1\}$. The value zero is used to represent non-membership, and the value one is used to represent membership. The truth or falsity of the statement "x is in A" is determined by the ordered pair $(x, \chi_A(x))$. The statement is true if the second element of the ordered pair is 1, and the statement is false if it is 0.

Similarly, a *fuzzy subset* A of a set X can be defined as a set of ordered pairs, each with the first element from X, and the second element from the interval $[0, 1]$, with exactly one ordered pair present for each element of X. This defines a mapping,

$$\mu_A\colon X \to [0, 1],$$

between elements of the set X and values in the interval $[0, 1]$. The value zero is used to represent complete non-membership, the value one is used

C. Carlsson et al., *Fuzzy Logic in Management*

to represent complete membership, and values in between are used to represent intermediate degrees of membership. The set X is referred to as the universe of discourse for the fuzzy subset A. Frequently, the mapping μ_A is described as a function, the membership function of A. The degree to which the statement "x is in A" is true is determined by finding the ordered pair $(x, \mu_A(x))$. The degree of truth of the statement is the second element of the ordered pair.

Definition 2.1. *[9] Let X be a nonempty set. A fuzzy set A in X is characterized by its membership function*

$$\mu_A \colon X \to [0, 1],$$

and $\mu_A(x)$ is interpreted as the degree of membership of element x in fuzzy set A for each $x \in X$.

It should be noted that the terms *membership function* and *fuzzy subset* get used interchangeably and frequently we will write simply $A(x)$ instead of $\mu_A(x)$. The family of all fuzzy (sub)sets in X is denoted by $\mathcal{F}(X)$. Fuzzy subsets of the real line are called *fuzzy quantities.*

Example 2.1. *The membership function of the fuzzy set of* real *numbers "close to 1", is can be defined as*

$$A(t) = \exp(-\beta(t-1)^2),$$

where β is a positive real number.

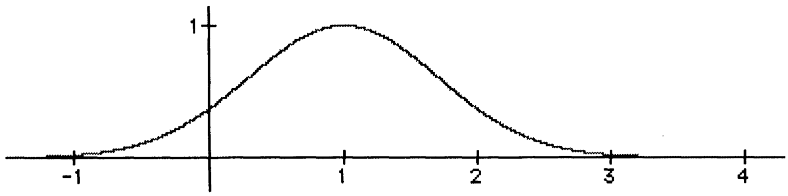


Figure 2.1. A membership function for "x is close to 1".

Let A be a fuzzy subset of X; the *support* of A, denoted supp(A), is the crisp subset of X whose elements all have nonzero membership grades in A. A fuzzy subset A of X is called *normal* if there exists an $x \in X$ such that $A(x) = 1$. An α-level set (or α-cut) of a fuzzy set A of X is a non-fuzzy set denoted by $[A]^\alpha$ and defined by $[A]^\alpha = \{t \in X | A(t) \geq \alpha\}$ if $\alpha > 0$, and cl(supp$A$), if $\alpha = 0$, where cl(supp$A$) denotes the closure of the support of A. A fuzzy set A of X is called *convex* if $[A]^\alpha$ is a convex subset of X for all $\alpha \in [0, 1]$.

In many situations people are only able to characterize numeric information imprecisely. For example, people use terms such as, about \$3,000, near zero, or essentially bigger than \$5,000. These are examples of what are called *fuzzy numbers.* Using the theory of fuzzy subsets we can represent these fuzzy numbers as fuzzy subsets of the set of real numbers. More exactly,

Definition 2.2. *A fuzzy number A is a fuzzy set of the real line with a normal, (fuzzy) convex and continuous membership function of bounded support. The family of fuzzy numbers will be denoted by $\mathcal{F}$.*

It is easy to see that the membership function of a fuzzy number A has the following properties:

(i) $\mu_A(t) = 0$, outside of some interval $[c, d]$;

(ii) there are real numbers a and b, $c \le a \le b \le d$ such that $\mu_A(t)$ is monotone increasing on the interval $[c, a]$ and monotone decreasing on $[b, d]$;

(iii) $\mu_A(t) = 1$ for each $x \in [a, b]$.

Let A be a fuzzy number. Then $[A]^\gamma$ is a closed convex (compact) subset of $\mathbb{R}$ for all $\gamma \in [0, 1]$. Let us introduce the notations

$$a_1(\gamma) = \min[A]^\gamma \text{ and } a_2(\gamma) = \max[A]^\gamma.$$

In other words, $a_1(\gamma)$ denotes the left-hand side and $a_2(\gamma)$ denotes the right-hand side of the γ-cut. We shall use the notation,

$$[A]^\gamma = [a_1(\gamma), a_2(\gamma)].$$

Definition 2.3. *A fuzzy set A is called triangular fuzzy number with peak (or center) a, left width $\alpha > 0$ and right width $\beta > 0$ if its membership function has the following form*

$$A(t) = \begin{cases} 1 - \dfrac{a-t}{\alpha} & \text{if } a - \alpha \le t \le a, \\ 1 - \dfrac{t-a}{\beta} & \text{if } a \le t \le a + \beta, \\ 0 & \text{otherwise}, \end{cases}$$

and we use the notation $A = (a, \alpha, \beta)$. It can easily be verified that

$$[A]^\gamma = [a - (1-\gamma)\alpha, a + (1-\gamma)\beta], \ \forall \gamma \in [0, 1].$$

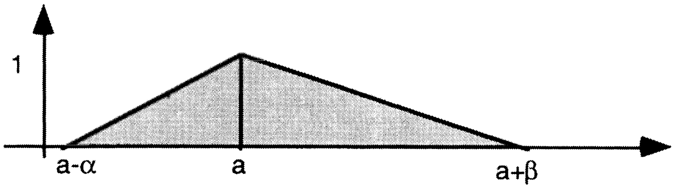


Figure 2.2. Triangular fuzzy number.

A triangular fuzzy number with center a may be seen as a fuzzy quantity

"x is approximately equal to a".

Definition 2.4. *A fuzzy set A is called trapezoidal fuzzy number with tolerance interval $[a, b]$, left width α and right width β if its membership function has the following form*

$$A(t) = \begin{cases} 1 - \dfrac{a-t}{\alpha} & \textit{if } a - \alpha \le t \le a \\ 1 & \textit{if } a \le t \le b \\ 1 - \dfrac{t-b}{\beta} & \textit{if } a \le t \le b + \beta \\ 0 & \textit{otherwise} \end{cases}$$

and we use the notation

$$A = (a, b, \alpha, \beta). \tag{2.1}$$

It can easily be shown that $[A]^\gamma = [a - (1-\gamma)\alpha, b + (1-\gamma)\beta]$ *for all* $\gamma \in [0, 1]$.

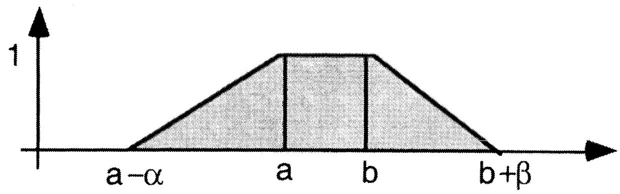


Figure 2.3. Trapezoidal fuzzy number.

A trapezoidal fuzzy number may be seen as a fuzzy quantity

"x is approximately in the interval $[a, b]$".

Definition 2.5. *Any fuzzy number $A \in \mathcal{F}$ can be described as*

$$A(t) = \begin{cases} L\left(\frac{a-t}{\alpha}\right) & \text{if } t \in [a-\alpha, a] \\ 1 & \text{if } t \in [a,b] \\ R\left(\frac{t-b)}{\beta}\right) & \text{if } t \in [b, b+\beta] \\ 0 & \text{otherwise} \end{cases}$$

where $[a,b]$ is the peak *or* core *of A,*

$$L\colon [0,1] \to [0,1], \quad R\colon [0,1] \to [0,1],$$

are continuous and non-increasing shape functions with $L(0) = R(0) = 1$ and $R(1) = L(1) = 0$. We call this fuzzy interval of LR-type and refer to it by

$$A = (a, b, \alpha, \beta)_{LR},$$

The support of A is $(a-\alpha, b+\beta)$.

Definition 2.6. *Let $A = (a, b, \alpha, \beta)_{LR}$ be a fuzzy number of type LR. If $a = b$ then we use the notation*

$$A = (a, \alpha, \beta)_{LR}, \tag{2.2}$$

and say that A is a quasi-triangular fuzzy number. Furthermore if $L(x) = R(x) = 1 - x$, then instead of $A = (a, b, \alpha, \beta)_{LR}$ we simply write

$$A = (a, b, \alpha, \beta).$$

Let A and B are fuzzy subsets of X. We say that A is a subset of B, and write $A \subset B$, if $A(t) \le B(t)$ for all $t \in X$.

Classical set theoretic operations from ordinary set theory can be extended to fuzzy sets. We note that all those operations which are extensions of crisp concepts reduce to their usual meaning when the fuzzy subsets have membership degrees that are drawn from $\{0,1\}$. For this reason, when extending operations to fuzzy sets we use the same symbol as in set theory. Let A and B are fuzzy subsets of $X \ne \emptyset$.

Definition 2.7. *The intersection of A and B is defined as*

$$(A \cap B)(t) = \min\{A(t), B(t)\},$$

for all $t \in X$.

Definition 2.8. *The union of A and B is defined as*

$$(A \cup B)(t) = \max\{A(t), B(t)\},$$

for all $t \in X$.

Definition 2.9. *The complement of a fuzzy set A is defined as*

$$(\neg A)(t) = 1 - A(t),$$

for all $t \in X$.

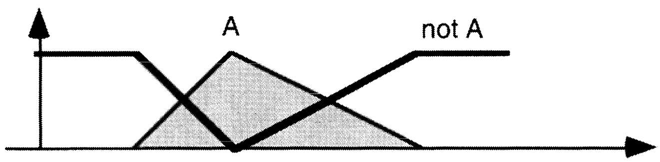


Figure 2.4. A and its complement.

Triangular norms were introduced by Schweizer and Sklar [7] to model distances in probabilistic metric spaces. In fuzzy sets theory triangular norms are extensively used to model logical connective *and.*

Definition 2.10. *A mapping*

$$T\colon [0,1] \times [0,1] \to [0,1]$$

is a triangular norm (t-norm for short) iff it is symmetric, associative, non-decreasing in each argument and $T(a,1) = a$, for all $a \in [0,1]$. In other words, any t-norm T satisfies the properties:

Symmetricity: $T(x,y) = T(y,x)$, $\forall x,y \in [0,1]$.

Associativity: $T(x,T(y,z)) = T(T(x,y),z)$, $\forall x,y,z \in [0,1]$.

Monotonicity: $T(x,y) \leq T(x',y')$ *if* $x \leq x'$ *and* $y \leq y'$.

One identy: $T(x,1) = x$, $\forall x \in [0,1]$.

These axioms attempt to capture the basic properties of set intersection. The basic t-norms are:

- minimum: $\min(a,b) = \min\{a,b\}$,
- Łukasiewicz: $T_L(a,b) = \max\{a+b-1, 0\}$,

- product: $T_P(a,b) = ab$,
- weak:

$$T_W(a,b) = \begin{cases} \min\{a,b\} & \text{if } \max\{a,b\} = 1, \\ 0 & \text{otherwise,} \end{cases}$$

- Hamacher [5]:

$$H_\gamma(a,b) = \frac{ab}{\gamma + (1-\gamma)(a+b-ab)}, \ \gamma \geq 0$$

- Dubois and Prade:

$$D_\alpha(a,b) = \frac{ab}{\max\{a,b,\alpha\}}, \ \alpha \in (0,1)$$

All t-norms may be extended, through associativity, to $n > 2$ arguments.

Triangular conorms are extensively used to model logical connective *or*.

Definition 2.11. *A mapping*

$$S\colon [0,1] \times [0,1] \to [0,1],$$

is a triangular co-norm (t-conorm) if it is symmetric, associative, non-decreasing in each argument and $S(a,0) = a$, for all $a \in [0,1]$. In other words, any t-conorm S satisfies the properties:

$S(x,y) = S(y,x)$ *(symmetricity)*

$S(x,S(y,z)) = S(S(x,y),z)$ *(associativity)*

$S(x,y) \leq S(x',y')$ *if* $x \leq x'$ *and* $y \leq y'$ *(monotonicity)*

$S(x,0) = x, \ \forall x \in [0,1]$ *(zero identy)*

The basic t-conorms are:

- maximum: $\max(a,b) = \max\{a,b\}$,
- Łukasiewicz: $S_L(a,b) = \min\{a+b,1\}$,
- probabilistic: $S_P(a,b) = a+b-ab$,
- strong:

$$STRONG(a,b) = \begin{cases} \max\{a,b\} & \text{if } \min\{a,b\} = 0, \\ 1 & \text{otherwise,} \end{cases}$$

- Hamacher:

$$HOR_\gamma(a,b) = \frac{a+b-(2-\gamma)ab}{1-(1-\gamma)ab}, \ \gamma \geq 0.$$

Lemma 2.1. *Let T be a t-norm. Then the following statement holds*

$$T_W(x,y) \leq T(x,y) \leq \min\{x,y\}, \ \forall x,y \in [0,1].$$

Lemma 2.2. *Let S be a t-conorm. Then the following statement holds*

$$\max\{a,b\} \leq S(a,b) \leq STRONG(a,b), \ \forall a,b \in [0,1]$$

The operation *intersection* can be defined by the help of triangular norms.

Definition 2.12. *The t-norm-based intersection of A and B is defined by the following membership function,*

$$(A \cap B)(t) = A(t) * B(t),$$

where $*$ denotes a t-norm, for all $t \in X$.

1.1 Fuzzy Relations

A classical relation can be considered as a set of tuples, where a tuple is an ordered pair. A binary tuple is denoted by (u,v), an example of a ternary tuple is (u,v,w) and an example of n-ary tuple is $(x_1,\dots,x_n)$.

Definition 2.13. *Let $X_1,\dots,X_n$ be classical sets. The subsets of the Cartesian product $X_1 \times \cdots \times X_n$ are called n-ary relations. If $X_1 = \cdots = X_n$ and $R \subset X^n$ then R is called an n-ary relation in X. Let R be a binary relation in $\mathbb{R}$. Then the characteristic function of R is defined as*

$$\chi_R(u,v) = \begin{cases} 1 & \text{if } (u,v) \in R, \\ 0 & \text{otherwise.} \end{cases}$$

If R is a binary relation and $(u,v) \in R$ then sometimes we will write uRv.

Example 2.2. *Let X be the domain of men {John, Charles, James} and Y the domain of women {Diana, Rita, Eva}, then the relation "married to" on $X \times Y$ is, for example*

{(Charles, Diana), (John, Eva), (James, Rita)}

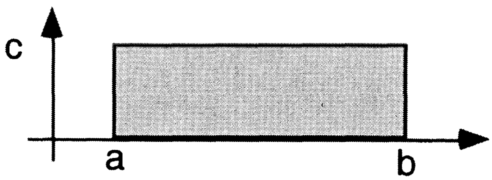


Figure 2.5. Graph of a crisp relation.

Example 2.3. *Consider the following relation $(u, v) \in R$ iff $u \in [a, b]$ and $v \in [0, c]$:*

$$\chi_R(u, v) = \begin{cases} 1 & \text{if } (u, v) \in [a, b] \times [0, c], \\ 0 & \text{otherwise.} \end{cases}$$

Definition 2.14. *Let R be a binary relation in a classical set U. Then*

- *R is reflexive if $\forall u \in U$: $(u, u) \in R$*
- *R is anti-reflexive if $\forall u \in U$: $(u, u) \notin R$*
- *R is symmetric if $(u, v) \in R$ entails $(v, u) \in R$*
- *R is anti-symmetric if $(u, v) \in R$ and $(v, u) \in R$ then $u = v$*
- *R is transitive if $(u, v) \in R$ and $(v, w) \in R$ then $(u, w) \in R$ for all $u, v, w \in U$.*

Example 2.4. *Consider the classical inequality relations on the real line $\mathbb{R}$. It is clear that $\leq$ is reflexive, anti-symmetric and transitive, while $<$ is anti-reflexive, anti-symmetric and transitive.*

Other important classes of binary relations are the following:

Definition 2.15. *R is an equivalence relation if, R is reflexive, symmetric and transitive*

Definition 2.16. *R is a partial order relation if it is reflexive, anti-symmetric and transitive*

Definition 2.17. *R is a total order relation if it is partial order and $(u, v) \in R$ or $(v, u) \in R$ hold for any u and v.*

Example 2.5. *Let us consider the binary relation "subset of". It is clear that it is a partial order relation. The relation $\leq$ on natural numbers is a total order relation.*

Example 2.6. *Consider the relation "mod 3" on natural numbers*

$$\{(m,n) \mid (n-m) \ mod \ 3 \ \equiv 0\}$$

This is an equivalence relation.

Definition 2.18. *Let X and Y be nonempty sets. A fuzzy relation R is a fuzzy subset of $X \times Y$. In other words, $R \in \mathcal{F}(X \times Y)$. If $X = Y$ then we say that R is a binary fuzzy relation in X.*

Let R be a binary fuzzy relation on $\mathbb{R}$. Then $R(u,v)$ is interpreted as the degree of membership of (u,v) in R.

Example 2.7. *A simple example of a binary fuzzy relation on $U = \{1,2,3\}$, called "approximately equal" can be defined as*

$$R(1,1) = R(2,2) = R(3,3) = 1,$$
$$R(1,2) = R(2,1) = R(2,3) = R(3,2) = 0.8,$$
$$R(1,3) = R(3,1) = 0.3.$$

The membership function of R is given by

$$R(u,v) = \begin{cases} 1 & \text{if } u = v, \\ 0.8 & \text{if } |u-v| = 1, \\ 0.3 & \text{if } |u-v| = 2. \end{cases}$$

In matrix notation it can be represented as

$$R = \begin{pmatrix} & 1 & 2 & 3 \\ 1 & 1 & 0.8 & 0.3 \\ 2 & 0.8 & 1 & 0.8 \\ 3 & 0.3 & 0.8 & 1 \end{pmatrix}$$

Fuzzy relations are very important because they can describe interactions between (linguistic) variables.

1.2 The Extension Principle

In order to use fuzzy numbers and relations in any intellgent system we must be able to perform arithmetic operations with these fuzzy quantities. In particular, we must be able to to *add*, *subtract*, *multiply* and *divide* with fuzzy quantities. The process of doing these operations is called *fuzzy arithmetic*. In general the extension principle pays a fundamental role in enabling us to extend any point operations to operations involving fuzzy sets.

Let $A = (a_1, a_2, \alpha_1, \alpha_2)_{LR}$, and $B = (b_1, b_2, \beta_1, \beta_2)_{LR}$, be fuzzy numbers of LR-type. Using Zadeh's extension principle [9] we can verify the following rules for addition and subtraction of fuzzy numbers of LR type,

$$A + B = (a_1 + b_1, a_2 + b_2, \alpha_1 + \beta_1, \alpha_2 + \beta_2)_{LR}$$
$$A - B = (a_1 - b_2, a_2 - b_1, \alpha_1 + \beta_2, \alpha_2 + \beta_1)_{LR}$$

furthermore, if $\lambda \in \mathbb{R}$ is a real number then λA can be represented as

$$\lambda A = \begin{cases} (\lambda a_1, \lambda a_2, \alpha_1, \alpha_2)_{LR} & \text{if } \lambda \geq 0 \\ (\lambda a_2, \lambda a_1, |\lambda|\alpha_2, |\lambda|\alpha_1)_{LR} & \text{if } \lambda < 0 \end{cases}$$

In particular if $A = (a_1, a_2, \alpha_1, \alpha_2)$ and $B = (b_1, b_2, \beta_1, \beta_2)$ are fuzzy numbers of trapezoidal form then

$$A + B = (a_1 + b_1, a_2 + b_2, \alpha_1 + \beta_1, \alpha_2 + \beta_2) \tag{2.3}$$
$$A - B = (a_1 - b_2, a_2 - b_1, \alpha_1 + \beta_2, \alpha_2 + \beta_1). \tag{2.4}$$

If $A = (a, \alpha_1, \alpha_2)$ and $B = (b, \beta_1, \beta_2)$ are fuzzy numbers of triangular form then

$$A + B = (a + b, \alpha_1 + \beta_1, \alpha_2 + \beta_2),$$
$$A - B = (a - b, \alpha_1 + \beta_2, \alpha_2 + \beta_1)$$

and if $A = (a, \alpha)$ and $B = (b, \beta)$ are fuzzy numbers of symmetric triangular form then

$$A + B = (a + b,\ \alpha + \beta), \quad A - B = (a - b,\ \alpha + \beta), \quad \lambda A = (\lambda a,\ |\lambda|\alpha).$$

The above results can be generalized to linear combinations of fuzzy numbers.

Let A and B be fuzzy numbers with $[A]^\alpha = [a_1(\alpha), a_2(\alpha)]$ and $[B]^\alpha = [b_1(\alpha), b_2(\alpha)]$. Then it can easily be shown that

$$[A + B]^\alpha = [a_1(\alpha) + b_1(\alpha), a_2(\alpha) + b_2(\alpha)],$$
$$[A - B]^\alpha = [a_1(\alpha) - b_2(\alpha), a_2(\alpha) - b_1(\alpha)],$$
$$[\lambda A]^\alpha = \lambda [A]^\alpha,$$

where $[\lambda A]^\alpha = [\lambda a_1(\alpha), \lambda a_2(\alpha)]$ if $\lambda \geq 0$ and $[\lambda A]^\alpha = [\lambda a_2(\alpha), \lambda a_1(\alpha)]$ if $\lambda < 0$ for all $\alpha \in [0, 1]$, i.e. any α-level set of the extended sum of two fuzzy numbers is equal to the sum of their α-level sets.

These properties of extended operations *addition, subtraction* and *multiplication by scalar* of fuzzy fuzzy numbers of type LR are often used in *fuzzy neural networks*.

1.3 Fuzzy Implications

Let p = "x is in A" and q = "y is in B" be crisp propositions, where A and B are crisp sets for the moment. The implication $p \to q$ is interpreted as $\neg(p \wedge \neg q)$. The full interpretation of the material implication $p \to q$ is that the degree of truth of $p \to q$ quantifies to what extend q is at least as true as p, i.e.

$$\tau(p \to q) = \begin{cases} 1 & \text{if } \tau(p) \leq \tau(q) \\ 0 & \text{otherwise} \end{cases}$$

where $\tau(.)$ denotes the truth value of a proposition.

Consider the implication statement: if "pressure is high" then "volume is small". The membership function of the fuzzy set A = "big pressure" is defined by

$$A(u) = \begin{cases} 1 & \text{if } u \geq 5 \\ 1 - \dfrac{5-u}{4} & \text{if } 1 \leq u \leq 5 \\ 0 & \text{otherwise} \end{cases}$$

The membership function of the fuzzy set B, *small volume* is given by

$$B(v) = \begin{cases} 1 & \text{if } v \leq 1 \\ 1 - \dfrac{v-1}{4} & \text{if } 1 \leq v \leq 5 \\ 0 & \text{otherwise} \end{cases}$$

If p is a proposition of the form "u is A" where A is a fuzzy set, for example, "big pressure" and q is a proposition of the form "v is B" for example, "small volume" then $(A \to B)(u, v)$ is defined by,

$$(A \to B)(u, v) = I(A(u), B(v)),$$

where function I is called a fuzzy implication function. We shall use the notation $(A \to B)(u, v) = A(u) \to B(v)$. In our interpretation $A(u)$ is considered as the truth value of the proposition "u is big pressure", and $B(v)$ is considered as the truth value of the proposition "v is small volume".

$$u \text{ is big pressure} \to v \text{ is small volume} \equiv A(u) \to B(v)$$

One possible extension of material implication to implications with intermediate truth values is

$$A(u) \to B(v) = \begin{cases} 1 & \text{if } A(u) \leq B(v), \\ 0 & \text{otherwise.} \end{cases}$$

This implication operator is called *Standard Strict.*

$$\text{"4 is big pressure"} \rightarrow \text{"1 is small volume"}$$

$$= A(4) \rightarrow B(1) = 0.75 \rightarrow 1 = 1.$$

A smoother extension of the material implication is the *Gödel* implication, defined by,

$$A(u) \rightarrow B(v) = \begin{cases} 1 & \text{if } A(u) \le B(v), \\ B(v) & \text{otherwise.} \end{cases}$$

Using the definitions of negation and union of fuzzy subsets the material implication $p \rightarrow q = \neg p \vee q$ can be extended by

$$A(u) \rightarrow B(v) = \max\{1 - A(u), B(v)\}.$$

This operator is called *Kleene-Dienes* implication.

1.4 Linguistic Variables and Quantifiers

The use of fuzzy sets provides a basis for a systematic way for the manipulation of vague and imprecise concepts. In particular, we can employ fuzzy sets to represent linguistic variables. A linguistic variable can be regarded either as a variable whose value is a fuzzy number or as a variable whose values are defined in linguistic terms.

Definition 2.19. *A linguistic variable is characterized by a quintuple*

$$(x, T(x), U, G, M),$$

in which x is the name of variable; $T(x)$ is the term set of x, that is, the set of names of linguistic values of x with each value being a fuzzy number defined on U; G is a syntactic rule for generating the names of values of x; and M is a semantic rule for associating with each value its meaning.

For example, if *speed* is interpreted as a linguistic variable, then its term set T (speed) could be

$$T = \{\text{slow, moderate, fast, very slow, more or less fast, sligthly slow,} \dots\},$$

where each term in T (speed) is characterized by a fuzzy set in a universe of discourse $U = [0, 100]$. We might interpret

- *slow* as "a speed below about 40 mph"

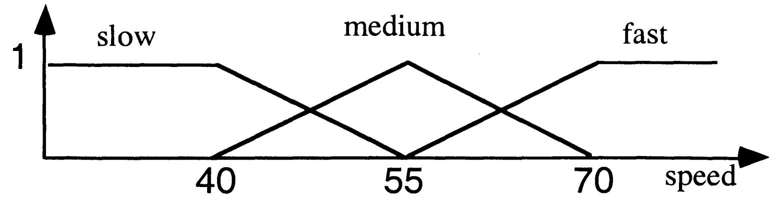


Figure 2.6. Values of linguistic variable *speed*.

- *moderate* as "a speed close to 55 mph"
- *fast* as "a speed above about 70 mph"

These terms can be characterized as fuzzy sets whose membership functions are

$$\text{slow}(v) = \begin{cases} 1 & \text{if } v \leq 40 \\ 1 - (v-40)/15 & \text{if } 40 \leq v \leq 55 \\ 0 & \text{otherwise} \end{cases}$$

$$\text{moderate}(v) = \begin{cases} 1 - |v-55|/30 & \text{if } 40 \leq v \leq 70 \\ 0 & \text{otherwise} \end{cases}$$

$$\text{fast}(v) = \begin{cases} 1 & \text{if } v \geq 70 \\ 1 - \dfrac{70-v}{15} & \text{if } 55 \leq v \leq 70 \\ 0 & \text{otherwise} \end{cases}$$

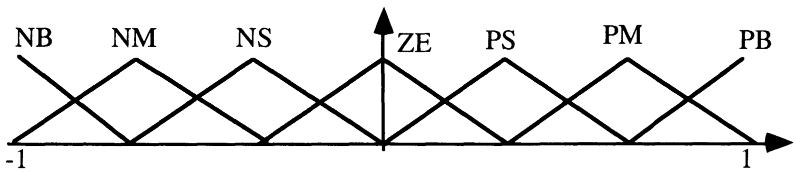


Figure 2.7. A usual fuzzy partition of $[-1, 1]$.

In many practical applications we normalize the domain of inputs and use the following type of fuzzy partition:

NVB	(Negative Very Big),	NB	(Negative Big),
NM	(Negative Medium),	NS	(Negative Small),
ZE	(Zero),	PS	(Positive Small),
PM	(Positive Medium),	PB	(Positive Big),
PVB	(Positive Very Big).		

A linguistic quantifier Q is a fuzzy set in $[0, 1]$. For instance, $Q =$ "most" may be given by its membership function as

$$\mu_{most}(x) = \begin{cases} 1 & \text{if } x \geq 0.8, \\ 2x - 0.6 & \text{if } 0.3 \leq x \leq 0.8, \\ 0 & \text{if } x \leq 0.3. \end{cases}$$

Throughout the paper we will use proportional linguistic quantifiers

$$\{\text{"most", "almost all", "much more than 75\%"},\ldots\},$$

since they are more appropriate in our context. For *absolute linguistic quantifiers* ("about 5", "much more than 7",...) the reasoning is similar.

Particularly important in our context are the non-decreasing fuzzy quantifiers defined by

$$x' > x" \Longrightarrow Q(x') > Q(x''),$$

for any $x', x" \in [0, 1]$.

A linguistically quantified proposition is exemplified by "most experts are convinced" and is generally written as

$$QY\text{'s are } F,$$

where Q is a linguistic quantifier (e.g., most), $Y = \{y\}$ is a set of objects (e.g., experts), and F is a property (e.g., convinced). Importance B may also be introduced

$$QBY\text{'s are } F,$$

e.g., "most (Q) of the important (B) experts ($Y's$) are convinced (F)".

The problem is basically to derive the truth values of quintified propositions (QY's are F) or (QBY's are F), from given truth values (y_i is F), for all $y_i \in Y$. This may be done by a fuzzy-logic-based calculus of linguistically quantified propositions [10] by

$$\text{truth}(QY\text{'s are } F) = \mu_Q\bigg(\frac{1}{p} \times \sum_{i=1}^{p} \mu_F(y_i)\bigg).$$

We rewrite "QBY's are F" as "Q (B and F) Y's are B" which leads to

$$\begin{aligned} \text{truth}(QBY\text{'s are } F) &= \text{truth}(Q \ (B \text{ and } F) \ Y\text{'s are } B) \\ &= \mu_Q\bigg(\frac{\sum_{i=1}^{p} \mu_B(y_i) * \mu_F(y_i)}{\sum_{i=1}^{p} \mu_B(y_i)}\bigg). \end{aligned}$$

where $*$ denotes a triangular norm.

1.5 A Theory of Approximate Reasoning

In 1979 *Zadeh* introduced a theory of approximate reasoning [13]. This theory provides a powerful framework for reasoning in the face of imprecise and uncertain information. Central to this theory is the representation of propositions as statements assigning fuzzy sets as values to variables. Suppose we have two interactive variables $x \in X$ and $y \in Y$ and the causal relationship between x and y is completely known. Namely, we know that y is a function of x, that is $y = f(x)$. Then we can make inferences easily

$$"y = f(x)" \ \& \ "x = x_1" \longrightarrow "y = f(x_1)".$$

This inference rule says that if we have $y = f(x)$, for all $x \in X$ and we observe that $x = x_1$ then y takes the value $f(x_1)$. More often than not we do not know the complete causal link f between x and y, only we now the values of $f(x)$ for some particular values of x, that is

$$\begin{array}{ll} \Re_1: & \text{If } x = x_1 \text{ then } y = y_1 \\ \Re_2: & \text{If } x = x_2 \text{ then } y = y_2 \\ & \qquad \dots \\ \Re_n: & \text{If } x = x_n \text{ then } y = y_n \end{array}$$

If we are given an $x' \in X$ and want to find an $y' \in Y$ which correponds to x' under the rule-base $\Re = \{\Re_1, \dots, \Re_m\}$ then we have an interpolation problem.

Let x and y be linguistic variables, e.g. "x is high" and "y is small". The basic problem of approximate reasoning is to find the membership function of the consequence C from the rule-base $\{\Re_1, \dots, \Re_n\}$ and the fact A.

$$\begin{array}{lll} \Re_1: & \text{if } x \text{ is } A_1 \text{ then } y \text{ is } C_1, & \\ \Re_2: & \text{if } x \text{ is } A_2 \text{ then } y \text{ is } C_2, & \\ & \dots\dots\dots\dots & \\ \Re_n: & \text{if } x \text{ is } A_n \text{ then } y \text{ is } C_n & \\ \text{fact:} & \quad x \text{ is } A & \\ \hline \text{consequence:} & & y \text{ is } C \end{array}$$

In fuzzy logic and approximate reasoning, the most important fuzzy inference rule is the *Generalized Modus Ponens* (GMP).

The classical *Modus Ponens* inference rule says: If p is true and $p \rightarrow q$ is true then q is true. If we have fuzzy sets, $A \in \mathcal{F}(U)$ and $B \in \mathcal{F}(V)$, and a fuzzy implication operator in the premise, and the fact is also a fuzzy set, $A' \in \mathcal{F}(U)$, then the consequnce, $B' \in \mathcal{F}(V)$, can be derived from the premise and the fact using the compositional rule of inference suggested by Zadeh [12]. The *Generalized Modus Ponens* inference rule says

premise	if x is A then	y is B
fact	x is A'	
consequence:		y is B'

where the consequence B' is determined as a composition of the fact and the fuzzy implication operator

$$B' = A' \circ (A \to B)$$

that is,

$$B'(v) = \sup_{u \in U} \min\{A'(u), (A \to B)(u, v)\}, \ v \in V.$$

The consequence B' is nothing else but the shadow of $A \to B$ on A'. The *Generalized Modus Ponens*, which reduces to classical modus ponens when $A' = A$ and $B' = B$, is closely related to the forward data-driven inference which is particularly useful in the *Fuzzy Logic Control.*

In many practical cases instead of sup-min composition we use sup-T composition, where T is a t-norm.

Definition 2.20. *(sup-T compositional rule of inference)*

premise	*if x is A then*	*y is B*
fact	*x is A'*	
consequence:		*y is B'*

where the consequence B' is determined as a composition of the fact and the fuzzy implication operator

$$B' = A' \circ (A \to B)$$

that is,

$$B'(v) = \sup\{T(A'(u), (A \to B)(u, v)) \mid u \in U\}, \ v \in V.$$

It is clear that T can not be chosen independently of the implication operator.

Example 2.8. *The GMP with Larsen's product implication, where the membership function of the consequence B' is defined by*

$$B'(y) = \sup \min\{A'(x), A(x)B(y)\},$$

for all $y \in \mathbb{R}$.

1.6 Possibilistic Mean Value and Variance of Fuzzy Numbers

In 1987 Dubois and Prade [4] defined an interval-valued expectation of fuzzy numbers, viewing them as consonant random sets. They also showed that this expectation remains additive in the sense of addition of fuzzy numbers. Following Carlsson and Fullér [3] we will recall the definitions of possibilistic mean value and variance of fuzzy numbers.

Let $A \in \mathcal{F}$ be a fuzzy number with with $[A]^\alpha = [a_1(\alpha), a_2(\alpha)]$. The *possibilistic mean value* of A is defined by,

$$\bar{M}(A) = \int_0^1 \gamma(a_1(\gamma) + a_2(\gamma))\gamma d\gamma$$

Example 2.9. *Let $A = (a, \alpha, \beta)$ be a triangular fuzzy number with center a, left-width $\alpha > 0$ and right-width $\beta > 0$ then a γ-level of A is computed by*

$$[A]^\gamma = [a - (1-\gamma)\alpha, a + (1-\gamma)\beta], \ \forall \gamma \in [0,1],$$

that is,

$$M_*(A) = 2\int_0^1 \gamma[a - (1-\gamma)\alpha d\gamma = a - \frac{\alpha}{3},$$

$$M^*(A) = 2\int_0^1 \gamma[a + (1-\gamma)\beta]d\gamma = a + \frac{\beta}{3},$$

and therefore,

$$M(A) = \left[a - \frac{\alpha}{3}, a + \frac{\beta}{3}\right],$$

and, finally,

$$\bar{M}(A) = \int_0^1 \gamma[a - (1-\gamma)\alpha + a + (1-\gamma)\beta]d\gamma = a + \frac{\beta - \alpha}{6}.$$

Specially, when $A = (a, \alpha)$ is a symmetric triangular fuzzy number we get $\bar{M}(A) = a$.

The ppossibilistic variance of $A \in \mathcal{F}$ is defined by

$$\text{Var}(A) == \frac{1}{2}\int_0^1 \gamma\big(a_2(\gamma) - a_1(\gamma)\big)^2 d\gamma,$$

and its standard deviation is defined by

$$\sigma_A = \sqrt{\text{Var}(A)}.$$

Example 2.10. *If $A = (a, \alpha, \beta)$ is a triangular fuzzy number then*

$$\mathrm{Var}(A) = \frac{1}{2}\int_0^1 \gamma\big(a + \beta(1-\gamma) - (a - \alpha(1-\gamma))\big)^2 d\gamma$$
$$= \frac{(\alpha+\beta)^2}{24}.$$

especially, if $A = (a, \alpha)$ is a symmetric triangular fuzzy number then

$$\mathrm{Var}(A) = \frac{\alpha^2}{6}.$$

If A is the characteristic function of the crisp interval $[a, b]$ then

$$\mathrm{Var}(A) = \frac{1}{2}\int_0^1 \gamma(b-a)^2 d\gamma = \left(\frac{b-a}{2}\right)^2$$

that is,

$$\sigma_A = \frac{b-a}{2}, \quad \bar{M}(A) = \frac{a+b}{2}.$$

The covariance between fuzzy numbers A and B is defined as

$$\mathrm{Cov}(A, B) = \frac{1}{2}\int_0^1 \gamma(a_2(\gamma) - a_1(\gamma))(b_2(\gamma) - b_1(\gamma))d\gamma.$$

Let $A = (a, \alpha)$ and $B = (b, \beta)$ be symmetric trianglar fuzzy numbers. Then

$$\mathrm{Cov}(A, B) = \frac{\alpha\beta}{6}.$$

The following theorem [3] shows that the variance of linear combinations of fuzzy numbers can easily be computed (in the same manner as in probability theory).

Theorem 2.1. *Let $\lambda, \mu \in \mathbb{R}$ and let A and B be fuzzy numbers. Then*

$$\mathrm{Var}(\lambda A + \mu B) = \lambda^2 \mathrm{Var}(A) + \mu^2 \mathrm{Var}(B) + 2|\lambda\mu| \mathrm{Cov}(A, B),$$

where the addition and multiplication by a scalar of fuzzy numbers is defined by the sup-min extension principle.

As a special case of Theorem 2.1 we get $\mathrm{Var}(\lambda A) = \lambda^2 \mathrm{Var}(A)$ for any $\lambda \in \mathbb{R}$ and

$$\mathrm{Var}(A + B) = \mathrm{Var}(A) + \mathrm{Var}(B) + 2\mathrm{Cov}(A, B).$$

Another important question is the relationship between the subsethood and the variance of fuzzy numbers. One might expect that $A \subset B$ (that is $A(x) \leq B(x)$ for all $x \in \mathbb{R}$) should imply the relationship $\text{Var}(A) \leq \text{Var}(B)$ because A is considered a "stronger restriction" than B. The following theorem [3] shows that subsethood does entail smaller variance.

Theorem 2.2. *Let $A, B \in \mathcal{F}$ with $A \subset B$. Then* $\text{Var}(A) \leq \text{Var}(B)$.

2. Averaging operators

Fuzzy set theory provides a host of attractive aggregation connectives for integrating membership values representing uncertain information. These connectives can be categorized into the following three classes *union, intersection* and *compensation* connectives.

Union produces a high output whenever any one of the input values representing degrees of satisfaction of different features or criteria is high. Intersection connectives produce a high output only when all of the inputs have high values. Compensative connectives have the property that a higher degree of satisfaction of one of the criteria can compensate for a lower degree of satisfaction of another criteria to a certain extent. In the sense, union connectives provide full compensation and intersection connectives provide no compensation. In a decision process the idea of *trade-offs* corresponds to viewing the global evaluation of an action as lying between the *worst* and the *best* local ratings. This occurs in the presence of conflicting goals, when a compensation between the corresponding compabilities is allowed. Averaging operators realize trade-offs between objectives, by allowing a positive compensation between ratings.

Definition 2.21. *An averaging operator M is a function $M\colon [0,1] \times [0,1] \to [0,1]$, satisfying the following properties*

- *Idempotency:* $M(x,x) = x, \ \forall x \in [0,1]$,
- *Commutativity:* $M(x,y) = M(y,x), \ \forall x, y \in [0,1]$,
- *Extremal conditions:* $M(0,0) = 0, \quad M(1,1) = 1$,
- *Monotonicity:* $M(x,y) \leq M(x',y')$ *if* $x \leq x'$ *and* $y \leq y'$,
- *M is continuous.*

Averaging operators represent a wide class of aggregation operators. We prove that whatever is the particular definition of an averaging operator, M, the global evaluation of an action will lie between the *worst* and the *best* local ratings:

Table 2.1. Mean operators.

Name	$M(x,y)$
harmonic mean	$2xy/(x+y)$
geometric mean	$\sqrt{xy}$
arithmetic mean	$(x+y)/2$
dual of geometric mean	$1-\sqrt{(1-x)(1-y)}$
dual of harmonic mean	$(x+y-2xy)/(2-x-y)$
median	$\mathrm{med}(x,y,\alpha),\ \alpha \in (0,1)$
generalized p-mean	$((x^p+y^p)/2)^{1/p},\ p \geq 1$

Lemma 2.3. *If M is an averaging operator then*

$$\min\{x,y\} \leq M(x,y) \leq \max\{x,y\},\ \forall x,y \in [0,1]$$

An important family of averaging operators is formed by quasi-arithmetic means

$$M(a_1,\dots,a_n) = f^{-1}\left(\frac{1}{n}\sum_{i=1}^{n} f(a_i)\right)$$

This family has been characterized by Kolmogorov as being the class of all decomposable continuous averaging operators. For example, the quasi-arithmetic mean of a_1 and a_2 is defined by

$$M(a_1,a_2) = f^{-1}\left(\frac{f(a_1)+f(a_2)}{2}\right).$$

The next table shows the most often used mean operators.

The process of information aggregation appears in many applications related to the development of intelligent systems. One sees aggregation in neural networks, fuzzy logic controllers, vision systems, expert systems and multi-criteria decision aids. In [8] Yager introduced a new aggregation technique based on the ordered weighted averaging (OWA) operators.

Definition 2.22. *An OWA operator is a mapping $F\colon \mathbb{R}^n \to \mathbb{R}$, that has an associated weighting vector $W=(w_1,w_2,\dots,w_n)^T$ such as $w_i \in [0,1]$, $1 \leq i \leq n$, and $w_1+\cdots+w_n = 1$. Furthermore,*

$$F(a_1,\dots,a_n) = w_1b_1+\cdots+w_nb_n = \sum_{j=1}^{n} w_jb_j,$$

where b_j *is the* j*-th largest element of the bag* $\langle a_1, \dots, a_n \rangle$.

A fundamental aspect of this operator is the re-ordering step, in particular an aggregate a_i is not associated with a particular weight w_i but rather a weight is associated with a particular ordered position of aggregate. When we view the OWA weights as a column vector we shall find it convenient to refer to the weights with the low indices as weights at the top and those with the higher indices with weights at the bottom.

It is noted that different OWA operators are distinguished by their weighting function. It is easy to show that the OWA operators have the basic properties associated with an *averaging operator.*

In order to classify OWA operators in regard to their location between *and* and *or*, a measure of *orness*, associated with any vector W is introduce by Yager [8] as follows

$$\text{orness}(W) = \frac{1}{n-1} \sum_{i=1}^{n} (n-i) w_i.$$

It is easy to see that for any W the orness(W) is always in the unit interval. Furthermore, note that the nearer W is to an *or*, the closer its measure is to one; while the nearer it is to an *and*, the closer is to zero.

In [8] Yager defined the measure of dispersion (or entropy) of an OWA vector by

$$\text{disp}(W) = -\sum_{i=1}^{n} w_i \ln w_i.$$

We can see when using the OWA operator as an averaging operator disp(W) measures the degree to which we use all the aggregates equally.

An important application of the OWA operators is in the area of quantifier guided aggregations [8]. Assume

$$\{A_1, \dots, A_n\},$$

is a collection of criteria. Let x be an object such that for any criterion A_i, $A_i(x) \in [0, 1]$ indicates the degree to which this criterion is satisfied by x. If we want to find out the degree to which x satisfies "*all* the criteria" denoting this by $D(x)$, we get following Bellman and Zadeh [1]:

$$D(x) = \min\{A_1(x), \dots, A_n(x)\}. \tag{2.5}$$

In this case we are essentially requiring x to satisfy "A_1 and A_2 and $\cdots$ and A_n". If we desire to find out the degree to which x satisfies "*at least one* of the criteria", denoting this $E(x)$, we get

$$E(x) = \max\{A_1(x), \dots, A_n(x)\}.$$

In this case we are requiring x to satisfy "A_1 or A_2 or $\cdots$ or A_n".

In many applications rather than desiring that a solution satisfies one of these extreme situations, "all" or "at least one", we may require that x satisfies *most* or *at least half* of the criteria. Drawing upon Zadeh's concept [11] of linguistic quantifiers we can accomplish these kinds of quantifier guided aggregations.

Definition 2.23. *A quantifier* Q *is called*

- regular monotonically non-decreasing *if*

$$Q(0) = 0, \quad Q(1) = 1, \quad \textit{if } r_1 > r_2 \text{ then } Q(r_1) \geq Q(r_2).$$

- regular monotonically non-increasing *if*

$$Q(0) = 1, \quad Q(1) = 0, \quad \textit{if } r_1 < r_2 \text{ then } Q(r_1) \geq Q(r_2).$$

- regular unimodal *if*

$$Q(r) = \begin{cases} 0 & \textit{if } r = 0, \\ \text{monotone increasing} & \textit{if } 0 \leq r \leq a, \\ 1 & \textit{if } a \leq r \leq b, \ 0 < a < b < 1, \\ \text{monotone decreasing} & \textit{if } b \leq r \leq 1, \\ 0 & \textit{if } r = 1. \end{cases}$$

With $a_i = A_i(x)$ the overall valuation of x is $F_Q(a_1, \ldots, a_n)$ where F_Q is an OWA operator. The weights associated with this quantified guided aggregation are obtained as follows

$$w_i = Q\left[\frac{i}{n}\right] - Q\left[\frac{i-1}{n}\right],$$

for $i = 1, \ldots, n$.

2.1 The Paradigm of Decision Analysis

The paradigm of Decision Analysis (DA) aims at both a descriptive and a prescriptive treatment of decision-making, i.e. both to describe how people make decisions and to prescribe how they *should* make decisions in order to maximize their utility. Keeney and Raiffa (1976, [6]) summarize their paradigm in a five-step process (pp 5-7; here partly abbreviated):

1 Pre-analysis. We assume that there is a unitary decision maker who is undecided about the course of action he or she should take in a particular

problem. The problem has been identified and the viable action alternatives are given.

2 Structural analysis. The decision maker structures the qualitative anatomy of his problem. What choices can he make now? What choices can he defer? How can he make choices that are based on information learned along the way? What experiments can he perform? What information can he gather purposefully and what can he learn during the normal course of events without intentional intervention? These questions are put into an orderly package by a *decision tree.* ...The decision tree has nodes that are under the control of the decision maker ...and nodes that are not under his full control. ...We refer to these two nodes as *decision* nodes and *chance* nodes.

3 Uncertainty analysis. The decision maker assigns probabilities to the branches emanating from chance nodes. These assignments are made by artfully mixing various techniques and procedures based on past empirical data, on assumptions fed into and results taken from various stochastic, dynamic models, on expert testimony (duly calibrated, to take into account personal idiosyncrasies and biases resulting from conflict of interest positions), and on the subjective judgments of the decision maker. The assignments should be checked for internal consistencies.

4 Utility or value analysis. The decision maker assigns utility values to consequences associated with paths through the tree. ...In an actual problem, there would be associated with (a) path various economic and psychological costs and benefits that affect the decision maker and others whom the decision maker considers as part of his decision problem. The cognitive impacts are conceptually captured by associating with each path of the tree a consequence that completely describes the implications of that path. The decision maker should then encode his preferences for these consequences in terms of cardinal utility numbers. This measurement not only reflects the decision maker's ordinal rankings for different consequences (...), it also indicates his relative preferences for lotteries over these consequences. ...the assignment of utility numbers to consequences must be such that the maximization of *expected utility* becomes the appropriate criterion for the decision maker's optimal action.

5 optimization analysis. After the decision maker structures his problem, assigns probabilities and assigns utilities, he calculates his optimal strategy - the strategy that maximizes expected utility. This strategy indicates what he should do at the start of the decision tree and what choice he should make at every decision node he can possibly reach along the way.

In a preface to the 1993 edition of their book Keeney and Raiffa basically state that nothing much had to be changed from the edition published eighteen years earlier:

Decision analysis is widely recognized as a sound prescriptive theory. When a decision involves multiple objectives - and this is almost always the case with important problems - multi-attribute utility theory forms the basic foundations for applying decision analysis. The theory explicitly addresses the value trade-offs and uncertainties that are invariably at the center of multiple-objective decisions. The experience of numerous applications indicates that the theory available in 1976 is still the most relevant theory available today.

With the introduction of *soft decision analysis* we will start to take issue with a few of the underlying key assumptions of the paradigm.

2.2 An Agenda for Soft Decision Analysis

As a positive criticism of the DA paradigm we have collected the insights we have gained in an agenda for soft decision analysis (SDA) [2], which we hasten to add is not complete but - hopefully - an opening for focused research and continuing development.

3.1 Focus on decision problems, which are ill or semi-structured (in contrast with the problems solved by DA, which normally are described as well-structured). Find ways to deal with this type of decision problems.

3.1.1 the set of viable action alternatives is (i) unknown, or (ii) partly known and partly defined, or (iii) known, and is being defined.

3.1.2 the set of goals and objectives is (i) unknown, or (ii) partly known and partly defined, or (iii) known, and is being defined as part of the problem solving process.

3.1.3 the context is (i) unknown, or (ii) partly known and partly defined, or (iii) known, and is being defined as part of the problem solving process, or is (iv) known, and is adapting to the problem solving process.

3.2 The problem structuring process should adapt to ill and semi-structured problems, and should be more comprehensive than the DA. Find ways to enhance the problem structuring process.

3.2.1 combine cause-effect modelling and producer-product modelling to move from well-structured and semi-structured to ill-structured problems.

3.2.2 find or develop methods for evaluating choices of viable action alternatives at pre-chosen points of time, gradually and partly during the problem solving process, or for creating and evaluating options for decision making at some later point of time.

3.2.3 find or develop methods for evolutionary modelling, i.e. methods to interactively (or even automatically) adapt models to information learned during the problem solving process.

3.2.4 find or develop methods to help design, build and implement better cognitive tools to enhance (or replace) decision trees.

3.2.5 develop software tools to support interactive problem structuring processes.

3.3 The uncertainty analysis should move beyond the approximation of uncertainty with probability estimates and the use of subjective probabilities. Find ways to enhance the uncertainty analysis.

3.3.1 develop methods to use imprecision (missing data, uncertainty, spotty information, imperfect knowledge) in modelling with fuzzy sets, fuzzy logic, approximate reasoning, etc.

3.3.2 find or develop methods to handle subjective assessments in a consistent, systematic and rational way with, for instance, possibility theory.

3.3.3 develop an "assessment paradigm" to guide uncertainty analysis away from undue precision but towards sufficient consistency, when the uncertainty is decided either prior to or during the problem solving process.

3.4 The value analysis should move beyond the use of utility theory. Find ways to enhance the value analysis.

3.4.1 find or develop methods to combine subjective assessments and objective measurements in a value system so that the combination satisfies the guidelines of the "assessment paradigm".

3.4.2 develop methods to handle various forms of multiple criteria (attributes, objectives, goals) value analysis.

3.4.3 develop methods to use fuzzy number assessments as part of a multiple criteria value analysis.

3.5 The optimization analysis should move beyond finding the best path through a decision tree. Find ways to enhance the optimization analysis.

3.5.1 formulate the SDA paradigm to combine the elements of steps 3.1-3.4.

3.5.2 find or develop methods to find "the best possible & options" action program to guide a decision process in a context defined in steps 3.1-3.4. This action program could be called a soft optimal strategy and should allow for flexibility both on choice and implementation time.

3.5.3 develop software tools to support an interactive optimization analysis and to guide the problem solving process through bad or partial problem structures (for which we use multiple data sources), imprecision, uncertainty, multiple criteria and value systems, which combine measurements and assessments.

The *Soft Decision Analysis* is focused on the "new economy" decision context where fast and correct decision making is becoming instrumental as the context is becoming more and more complex, and will change more and more rapidly. There is no great consensus on what exactly will form the "new economy" context, but some of the key elements will most probably be, (i) virtual teamwork in different places and in different time zones, (ii) decision support systems on mobile devices, with (iii) access to and the use of multilayer networks (Internet(s), intranets), through which (iv) access to and the use of a multitude of data sources (databases, data warehouses, text files, multimedia sources, etc.), and with support from (v) intelligent technologies for filtering, sifting and summarizing (software agents, machine intelligence, evolutionary computing, neural nets, etc.) and (vi) multiple criteria (crisp, soft) algorithms for problem solving.

References

[1] Bellman R.E. and Zadeh L.A., Decision-making in a fuzzy environment, *Management Sciences*, Ser. B 17(1970) 141-164.

[2] Carlsson C. and Fullér R., A position paper on agenda for soft decision analysis, *Fuzzy Sets and Systems*, 131(2002) 3-11.

[3] Carlsson C. and Fullér R., On possibilistic mean value and variance of fuzzy numbers, *Fuzzy Sets and Systems*, 122(2001) 139-150.

[4] Dubois D. and Prade H., The mean value of a fuzzy number, *Fuzzy Sets and Systems* 24(1987) 279-300.

[5] Hamacher H., Über logische Aggregationen nicht binär explizierter Entscheidung-kriterien (Rita G. Fischer Verlag, Frankfurt, 1978).

[6] Keeny R.L. and Raiffa H., *Decisions with Multiple Objectives*, John Wiley & Sons, 1976.

[7] Schweizer B. and Sklar A., Associative functions and abstract semigroups, *Publ. Math. Debrecen*, 10(1963) 69-81.

[8] Yager R.R., Ordered weighted averaging aggregation operators in multi-criteria decision making, *IEEE Trans. on Systems, Man and Cybernetics*, 18(1988) 183-190.

[9] Zadeh L.A., Fuzzy Sets, *Information and Control*, 8(1965) 338-353.

[10] Zadeh L.A., "A Computational Approach to Fuzzy Quantifiers in Natural Languages", Computer Mathematics with applications, 9, 1983, 149-183.

[11] Zadeh L.A., A computational theory of dispositions, *Int. Journal of Intelligent Systems*, 2(1987) 39-63.

[12] Zadeh, L.A., Outline of a New Approach to the Analysis of Complex Systems and Decision Processes, IEEE Transactions on Systems, Man and Cybernetics, SMC-3 1973.

[13] Zadeh L.A., A theory of approximate reasoning, In: J.Hayes, D.Michie and L.I.Mikulich eds., *Machine Intelligence, Vol.9* (Halstead Press, New York, 1979) 149-194

Chapter 3

GROUP DECISION SUPPORT SYSTEMS

No one works completely independently. Almost everyone is part of at least one group, typically several groups at any point in time. Groups communicate, share information, generate ideas, organize ideas, draft policies and procedures, collaborate on the writing of reports, share a vision, build consensus, makes decisions and so on. [89]

Recently, technological developments, such as electronic communication, computing and decision support, coupled with growing interest in improving meetings effectiveness in organizations have encouraged research and applications in Group Decision Support Systems (GDSS). De Sanctis and Gallupe [22] defined GDSS as integrated computer-based systems that facilitate solution of semi- or unstructured problems by a group that has joint responsibility for making the decision. Nowadays the complexity of decision processes is increasing dramatically and decisions must be taken more quickly.

The first aim of GDSS is to improve the process of decision making providing methodologies and techniques to facilitate modeling and solution of complex and not well structured problems by a group of agents. In a multiagent decision making environment many difficulties arises, e.g. the objectives are not clear and measurable, the decisions must be taken under time pressure, the information is incomplete, complexity and uncertainty are dominant, objectives/criteria are conflicting.

As Sprague [104] pointed out, one of the most important dimensions of group decision support is the communication and coordination between decision makers vertically and horizontally. The GDSS must play a role in integrating functional subunits horizontally, and in integrating long-range, medium-range and short-range planning to create a coordinated strategy [28].

De Sanctis and Gallupe [21] introduced three different levels of approach to supporting the group decision making. Level 1 GDSS improve the decision process by facilitating information exchange among members via computer-supported conference rooms or electronic board rooms.

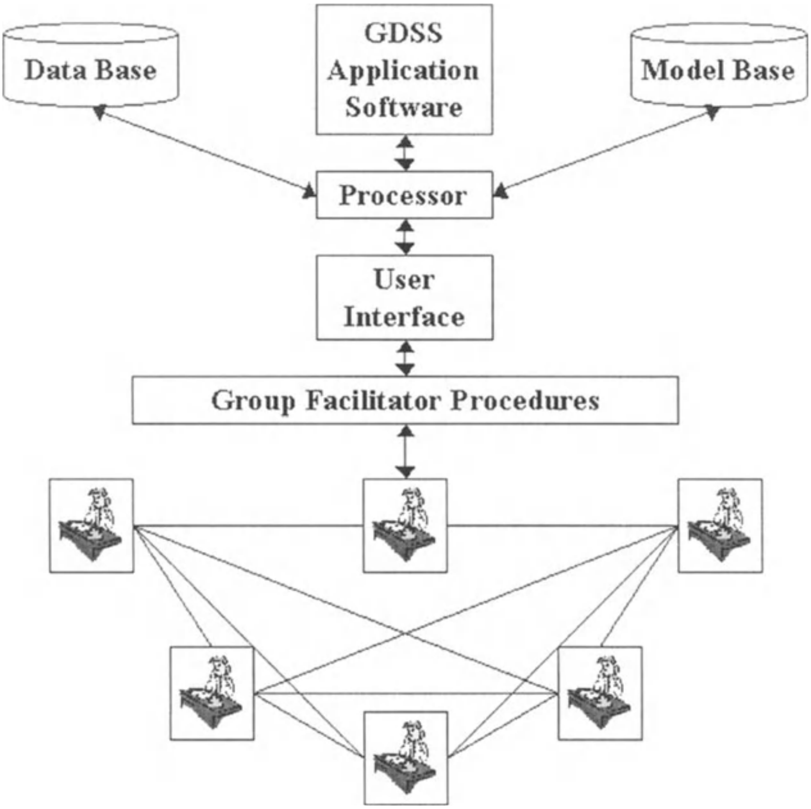


Figure 3.1. Structure of a GDSS.

Level 2 GDSS provide decision modeling and group decision techniques aimed at reducing uncertainty and 'noise' in the decision processes.

Level 3 GDSS are characterized by machine -induced group communication patterns and can include expert advice in selecting and arranging of rules to be applied during a meeting.

The *Model Base* is a critical component because it contains the group decision making procedures derived from the many formal approaches that have been developed over the years, and based on the numerous mathematically oriented methods used in their analysis.

Three epochs stand out in the development of methods of Group Decision Making (election and social choice). The first one occurred in France in the 1780s, the second one in England between 1860 and 1885, and the third one primarily in the United States between 1950 and 1975. Here we are more interested in the problem of social choice, i.e., how to aggregate individual preferences to determine a winning alternative, or several winners if more than one is to be chosen, or to determine a consensus ranking of the alternatives.

1. The Arrow Impossibility Theorem: From Classical to Fuzzy Approaches

It is widely agreed today that the most important advance in the theory of social choice during the past century was Arrow's discovery [2] that a few appealing criteria for social ranking methods are mutually incompatible. Its essential idea is that the problems that arise from Condorcet's paradox of voting, or cyclical majorities, cannot be avoided under any reasonable generalization of majority comparisons.

The crucial technical advance in Arrow's approach that led to the impossibility theorem was the consideration of a variety of individual preference profiles that might arise in a choice process involving three or more individuals.

Let $A = \{a, b, c, \ldots\}$ be a finite *set of candidates* (or social states), and $N = \{1, 2, 3, \ldots, n\}$ be a *set of voters.* We assume that A has at least three elements.

The preference relation of the i-th voter is an ordering R_i, i.e., it is a reflexive, complete, and transitive binary relation on A. Let R refer to the social preference relation. A collective choice rule is a function f such that for any n-tuple $\langle R_1, \ldots, R_n\rangle$ of individual prerefences a social preference relation R is determined

$$R = f(R_1, \ldots, R_n).$$

Here R is assumed to be an ordering, furthermore, f is called a social welfare function.

For any preference relation R, we define an *indifference* relation I on A by

$$a\, I\, b \iff a\, R\, b \;\&\; b\, R\, a,$$

for all a and b in A, and a *strict pereference* relation P on A by

$$a\, P\, b \iff a\, R\, b \;\&\; \mathrm{not}(b\, R\, a).$$

The concept of group decision making is not a precise one. *A prototype for this concept is a collection of individuals who - despite personal disagreements - are forced to reach a consensus.* This consensus can be either negotiated or computed according to some "democratic" rules. Particular collective choice rules are usually described in the social choice theory by means of their properties. Some well known properties are,

(U) (Unrestricted domain) f is defined for all logically possible combinations of indivuidual preferences;

(P) (Pareto optimality) $[(\forall i)(P_i(a,b) = 1] \rightarrow [P(a,b) = 1]$ for all a and b in A;

(I) Independence of irrelevant alternatives.

(D) (Nondictatorship) There is no individual i such that for every element of the domain of f

$$[P_i(a,b) = 1] \rightarrow [P(a,b) = 1],$$

for all $a, b \in A$.

The classical Arrow's Impossibility Theorem [2] states that there is no social welfare function satisfying conditions U, P, I, and D.

Let L be an ordered set of elements considered as truth values of some multiple valued logic. This set is assumed to be closed under propositional connectives $\vee$, $\wedge$, $\neg$, and $\rightarrow$, furthermore, its greatest element is denoted by 1.

Definition 3.1. *A function* $R\colon A \times A \rightarrow L$ *is said to be a* valued relation *on* A*, if it satisfies the following conditions:*

(r) $R(a,a) = 1$, *reflexivity*

(c) $R(a,b) \vee R(b,a) = 1$, *completeness*

(t) $[(R(a,b) \wedge R(b,c)) \rightarrow R(a,c)] = 1$, *transitivity,*

for all a, b *and* c *in* A *(*$a \neq b$ *in the second condition).*

The family of all valued relations on A will be denoted by $\mathrm{Val}(A, L)$. We define a *valued indifference* relation I on A by

$$I(a,b) = R(a,b) \wedge R(b,a),$$

for all a and b in A, and a *valued strict pereference* relation P on A by

$$P(a,b) = R(a,b) \wedge \neg R(b,a).$$

Suppose that we are given relations $R_1, R_2, \ldots, R_n$ from $\mathrm{Val}(A, L)$, then the problem is to determine a relation

$$R = f(R_1, R_2, \ldots, R_n)$$

satisfying the following conditions:

(U) (Unrestricted domain) f is defined for all logically possible combinations of indivuidual preferences;

(P) (Pareto optimality) $[(\forall i)(P_i(a,b) = 1] \rightarrow [P(a,b) = 1]$ for all a and b in A;

(I) Independence of irrelevant alternatives.

Assuming that L is the usual binary logic, Arrow proved that the only function f satisfying conditions (U), (P) and (I) is,

$$f(R_1, R_2, \ldots, R_n) = R_i,$$

for some i. This solution has been called a dictatorial one, and it is considered to be highly undesirable.

Admitting two different types of logics L_1 and L_2, (where L_1 is the usual, classic binary logic, whereas L_2 is a fuzzy logic with logical operations defined by

- $\alpha \wedge \beta = \max\{0, \alpha + \beta - 1\}$, $\alpha \vee \beta = \min\{\alpha + \beta, 1\}$,
- $\neg\alpha = 1 - \alpha$, $\alpha \rightarrow \beta = \min\{1 - \alpha + \beta, 1\}$)

Skala [83] managed to prove that function

$$f\colon \mathrm{Val}^n(A, L_1) \rightarrow \mathrm{Val}(A, L_2),$$

defined by

$$f(R_1, R_2, \ldots, R_n)(a,b) = \frac{1}{n}\sum_{i=1}^{n} R_i(a,b).$$

will satisfy conditions (U), (P), (I) and, additionally, the following condition,

(D) (Nondictatorship) There is no individual i such that for every element of the domain of f

$$[P_i(a,b) = 1] \rightarrow [P(a,b) = 1],$$

for all $a, b \in A$.

Ovchinnikov [91] proved that this function can be generalized as follows:

$$f(R_1, R_2, \ldots, R_n)(a, b) = \phi^{-1}\left[\frac{1}{n}\sum_{i=1}^{n} \phi(R_i(a, b))\right],$$

where $\phi\colon [0,1] \to [0,1]$ is any automorphism of the unit interval $[0,1]$.

Note 3.1. *In both cases the Arrowian paradox is resolved by introducing different types of logic for individual behaviour and for the group behaviour. It is possible however to maintain the same logical rules for individual and group behaviours but introducing different types of valuations.*

Let $d_i(x_i, x)$ denotes the grade of *distress* (or aversion) of i-th subject (expert) when his (her) decision x_i is replaced by any other decision x. It is supposed that each expert supplies two things: the decision x_i and the function $d_i\colon \{x_i\} \times X \to [0,1]$. This function has to satisfy the following two restrictions: $d_i(x_i, x) \geq 0$ and $d_i(x_i, x_i) = 0$. A group decision is then defined as an element x minimizing an overall (the group's) distress. Therefore, the problem is how to aggregate individual distresses to an overall distress.

A slightly different approach is the following: One assumes that each expert supplies not only decision x_i, but also a similarity relation

$$S_i\colon X \times X \to [0,1]$$

defined on the set of all possible decisions. Then a group decision is determined by maximizing the quantity

$$h(x) = \mathrm{Agg}\{S_1(x_i, x), \ldots, S_n(x_i, x)\},$$

where Agg is properly defined (according to some ethical principles) aggregation operator.

2. Consensus Modeling in GDM

This section concerns some issues related to group decision support systems, more specifically, we discuss some means for supporting the consensus reaching processes. These processes are an important part of group decision making, so we should find a proper place for them in GDSS. However, they are by no means the only aspect of group decision making.

The algorithms and software described in this section represent just a subsystem in the intended group decision support system though for brevity, we use the word "system", instead of "subsystem". Let us note here that the intended system is meant to support a wide spectrum of group-decision-making-related tasks, of which consensus reaching is just a small subset, since we share the view of many researchers and practitioners (see, e.g., [48]) that the greater the range of tasks supported by the system the more chance that it will be used (and survive). This opinion is also confirmed by our experience.

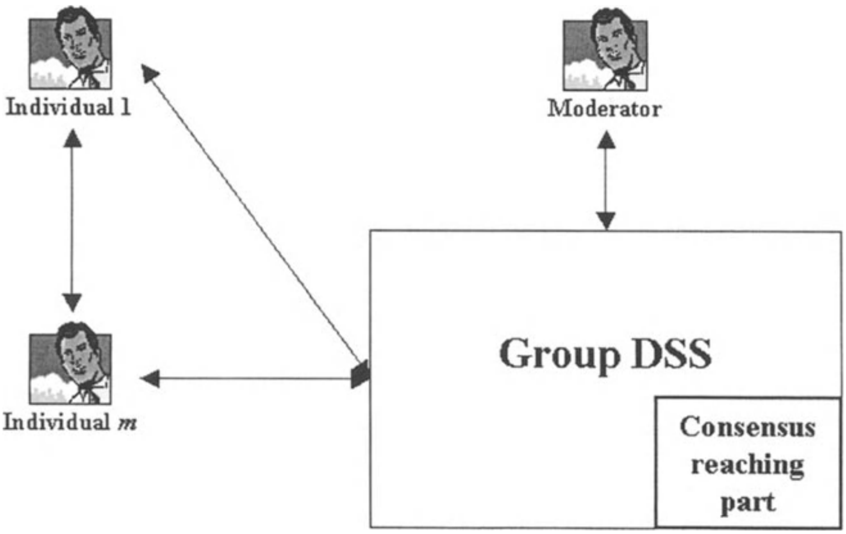


Figure 3.2. Group decision support system and its consensus-reaching part.

In the basic framework we have a set of individuals (experts, decision makers, ...) who present their opinions concerning an issue in question, and a distinguished person, called moderator, who is supposed to be responsible for the session with the individuals.

The individuals present their testimonies, which may initially differ to a large extent, i.e. the group may be far from consensus (unanimous agreement, as traditionally meant). Then, the moderator - via some exchange of information, rational argument, bargaining, etc. - tries to persuade the individuals to change their opinions. If the individuals are rationally committed to consensus, such a change usually occurs, and the group gets closer to consensus. This is repeated until the group gets sufficiently close to consensus, i.e. until the individual opinions become sufficiently similar, or until we reach some time limit meant for the process.

It is clear from the above that if the number of individuals is high enough and the form of their opinions is complex enough (as will be in our case), then it may be difficult for the moderator to assess how close to the consensus the group is. Thus, he or she needs a degree of consensus, as well as some effective communication means with the system and individuals. Both should be user-friendly and human-consistent.

We attain this, firstly, by using in the definition of our degree of consensus some elements of commonsense knowledge and of a natural language and secondly, by allowing elements of a natural language, computer graphics, interactive mode, etc. for communication.

The individual testimonies are expressed by fuzzy preference relations. This is a convenient representation of real-life preferences, which are often not clear-cut. Basically, if $S = (s_1, \ldots, s_n)$ is a set of options, then the fuzzy preference relation of individual k, denoted R_k, is given by its membership function $\mu_k \colon S \times S \to [0,1]$, such that $\mu_k(s_i, s_j)$ is the strength of preference of option s_i over option s_j as felt by individual k.

The degree of consensus is meant to be the degree to which "most of the individuals agree as to their preferences concerning almost all of the relevant options", furthermore, "most" and "almost all" may be replaced by any suitable linguistic quantifier. It takes its values from the unit interval, from 0 for a complete lack of consensus (dissensus) to 1 for full consensus, through all intermediate values. Notice that this new degree of consensus is certainly more realistic and human-consistent than conventional degrees.

As a formal tool for deriving the soft degree of consensus we use Zadeh's fuzzy-logic-based calculus of linguistically quantified proprieties. This calculus is a prerequisite for Zadeh's representation of commonsense knowledge as a collection of dispositions, i.e. propositions with implicit linguistic quantifiers. The use of this calculus in the development of our degree of consensus may be viewed as an attempt at introducing commonsense into the essence of consensus.

In Section 4 we will describe an interactive decision support system for consensus reaching processes based on the new degree of consensus. We will briefly present the structure of the system. Emphasis is on its use. We will present the main menus, helps, data elicitation modes. etc. All are user-friendly making much use of a quasi natural language, graphics, etc. Our notation concerning fuzzy sets is standard: for details, see, e.g. [58].

3. A Soft Degree of Consensus Based on Fuzzy Logic with Linguistic Quantifiers

In this Section we will present the idea of a *soft* degree of consensus as proposed by Kacprzyk (1987), and developed further by Kacprzyk and Fedrizzi (1986, 1988), and Fedrizzi and Kacprzyk (1988).

This degree is meant to overcome some "rigidness" of conventional degrees of consensus in which full consensus occurs only when "all the individuals agree as to all the issues". We should note here that the soft degree of consensus can be equal to one - which stands for full consensus - when, say, "most of the individuals agree as to almost all (of the relevant) issues".

Our point of departure is a set of individual fuzzy preference relations. If $S = (s_1, \ldots, s_n)$ is a set of options and $I = \{1, \ldots, m\}$ is a set of individuals, then a fuzzy preference relation of individual k, R_k, is given by its membership function $\mu_k \colon S \times S \to [0, 1]$, such that

$$\mu_k(s_i, s_j) = \begin{cases} 1 & \text{if } s_i \text{ is definitely preferred over } s_j, \\ c \in (0.5, 1) & \text{if } s_i \text{ is sligthly preferred over } s_j, \\ 0.5 & \text{if there is no preference (indifference)}, \\ b \in (0, 0.5) & \text{if } s_j \text{ is sligthly preferred over } s_i, \\ 0 & \text{if } s_j \text{ is definitely preferred over } s_i. \end{cases}$$

We will use the notation $r_{ij}^k = \mu_k(a_i, a_j)$, where $r_{ij}^k + r_{ji}^k = 1$, for all i, j, k.

The (soft) degree of consensus is now derived in three steps.

First, for each pair of individuals we derive a degree of agreement as to their preferences.

Second, we pool (aggregate) these degrees to obtain a degree of agreement of each pair of individuals as to their preferences between Q_1 (a linguistic quantifier as, e.g., '"most", "almost all", "mach more than 50%", ...) pairs of relevant options.

Third we aggregate these degrees to obtain a degree of agreement of Q_2 (a linguistic quantifier similar to Q_1) pairs of individuals as to their preferences between Q_1 pairs of relevant options. This is meant to be the degree of consensus sought.

The degree of *strict agreement* between individuals p and q as to their preferences between options s_i and s_j may thus be defined as,

$$v_{ij}(p, q) = \begin{cases} 1 & \text{if } r_{ij}^p = r_{ij}^q, \\ 0 & \text{otherwise.} \end{cases} \tag{3.1}$$

Relevance of the alternatives is assumed to be a fuzzy set defined over the set of options, $B \in \mathcal{F}(S)$, such that $\mu_B(s_i) \in [0, 1]$ is the degree of relevance of alternative s_i: from 0 standing for "definitely irrelevant" to 1 for "definitely relevant", through all intermediate values. For each pair of options $(s_i, s_j) \in S \times S$ we may now introduce the following index of relevance,

$$b_{ij}^B = \frac{\mu_B(s_i) + \mu_B(s_j)}{2}, \tag{3.2}$$

obviously are irrelevant, since they concern the same option, for all i, j, k.

The degree of agreement between individuals p and q as to their preferences between all the relevant pairs of options is

$$v_B(p,q) = \frac{\sum_{i=1}^{n-1}\sum_{j=i+1}^{n} v_{ij}(p,q) * b_{ij}^B}{\sum_{i=1}^{n-1}\sum_{j=i+1}^{n} b_{ij}^B}, \tag{3.3}$$

where $*$ denotes a t-norm.

The degree of agreement between individuals p and q as to their preferences between Q_1 relevant pairs of options is

$$v_{Q_1,B}(p,q) = \mu_{Q_1}(v_B(p,q)). \tag{3.4}$$

In turn, the degree of agreement of all the pairs of individuals as to their preferences between Q_1 relevant pairs of options is

$$V_{Q1,B} = \frac{2}{m(m-1)}\sum_{p=1}^{m-1}\sum_{q=p+1}^{m} v_{Q_1,B}(p,q), \tag{3.5}$$

and, finally, the degree of agreement of Q_2 pairs of individuals as to their preferences between Q_1 relevant pairs of options, called the degree of $Q_1/Q_2/B$-consensus, is

$$\text{con}_B(Q_1,Q_2) = \mu_{Q_2}(V_{Q_1,B}). \tag{3.6}$$

Since the strict agreement may be viewed too rigid, we can use the degree *of sufficient agreement* (at least to degree $\alpha \in [0,1]$) of individuals p and q as to their preferences between options si and sj, defined by

$$v_{ij}^{\alpha}(p,q) = \begin{cases} 1 & \text{if } 1-\alpha \le |r_{ij}^p - r_{ij}^q| \le 1, \\ 0 & \text{otherwise.} \end{cases} \tag{3.7}$$

Then, following this line of reasoning, we obtain the degree of sufficient agreement (at least to degree a) of Q_2 pairs of individuals as to their preferences between Q1 pairs of relevant options, called the degree of $\alpha/Q_1/Q_2/B$-consensus, given by

$$\text{con}_B^{\alpha}(Q_1,Q_2) = \mu_{Q_2}(V_{Q_1,B}^{\alpha}). \tag{3.8}$$

We can also explicitly introduce the strength of agreement into (3.1) and define the degree of strong agreement of individuals p and q as to their preferences between options s_i and s_j, e.g., as

$$v_{ij}^s(p,q) = s(r_{ij}^p - r_{ij}^q),$$

where $s : [0,1] \to [0,1]$ is some function representing the degree of strong agreements as, such that $x' < x'' \Longrightarrow s(x') \geq s(x'')$, for all $x', x'' \in [0,1]$, and $s(x) = 1$ for some $x \in [0,1]$, e.g.,

$$s(x) = \begin{cases} 1 & \text{if } x \leq 0.05, \\ -10x + 1.5 & \text{if } 0.05 \leq x \leq 0.15, \\ 0 & \text{otherwise.} \end{cases}$$

Then, following this reasoning, we obtain the degree of strong agreement of Q_2 pairs of individuals as to their preferences between Q_1 pairs of relevant options, called the degree of $s/Q_1/Q_2/B$-consensus, as

$$con_B^s(Q_1, Q_2) = \mu_{Q_2}(V_{Q_1,B}^s). \tag{3.9}$$

For more information on soft degrees of consensus, see [39,52,53,62].

Example 3.1. *Let the numbers of options, n, and individuals, m, be equal to four, and the individual fuzzy preference relations be (the irrelevant left lower triangular parts are omitted):*

$$R_1 = \begin{pmatrix} 0.4 & 0.7 & 0.1 \\ & 0.8 & 0.2 \\ & & 0.7 \end{pmatrix} \quad R_2 = \begin{pmatrix} 0.4 & 0.5 & 0.0 \\ & 0.8 & 0.2 \\ & & 0.7 \end{pmatrix}$$

$$R_3 = \begin{pmatrix} 0.4 & 0.4 & 0.3 \\ & 0.8 & 0.2 \\ & & 0.7 \end{pmatrix} \quad R_4 = \begin{pmatrix} 0.4 & 0.7 & 0.1 \\ & 0.7 & 0.1 \\ & & 0.7 \end{pmatrix}$$

The quantifier concerning the options, Q_1, the quantifier concerning the individuals Q_2, are both assumed to be "most" defined by

$$\mu_{most}(x) = \begin{cases} 1 & \textit{if } x \geq 0.8, \\ 2x - 0.6 & \textit{if } 0.3 < x < 0.8, \\ 0 & \textit{if } x \leq 0.3, \end{cases}$$

and the t-norm in (3.3) is the minimum, i.e.

$$a * b = \min\{a, b\}.$$

Suppose now that the relevance of the options is not accounted for, that is, it is assumed that $\mu_B(s_i) = 1$, for $s_i \in S$. First, we obtain the degree of agreement between individuals, p and q as to their preferences between all the relevant pairs of options as

$$v_B^s(p, q) = \begin{pmatrix} 0.67 & 0.67 & 0.67 \\ & 0.67 & 0.33 \\ & & 0.33 \end{pmatrix}$$

and the degree of agreement between individuals p and q as to their preferences between Q1 ("most") relevant pairs of options as

$$v_{Q_1,B}(p,q) = \begin{pmatrix} 0.73 & 0.73 & 0.73 \\ & 0.73 & 0.07 \\ & & 0.07 \end{pmatrix}$$

and, therefore,

$$\text{con}_B(\text{"most"}, \text{"most"}) = 0.4222.$$

Next, we assume that $\alpha = 0.9$. First, we obtain the degree of (sufficient, at least to degree $\alpha = 0.90$) agreement between individuals p and q as to their preferences between all the relevant pairs of options as

$$v_B^{0.9}(p,q) = \begin{pmatrix} 0.83 & 0.67 & 1.0 \\ & 0.83 & 0.83 \\ & & 0.67 \end{pmatrix}$$

and the degree of (sufficient, at least to degree $\alpha = 0.90$) agreement between individuals p and q as to their preferences between Q_1 ("most") relevant pairs of options as

$$v_{Q_1,B}^{0.9}(p,q) = \begin{pmatrix} 1.0 & 0.73 & 1.0 \\ & 1.0 & 1.0 \\ & & 0.73 \end{pmatrix}$$

and, therefore,

$$\text{con}_B^{0.9}(\text{"most"}, \text{"most"}) = 1.00.$$

Next, we assume that $s(x)$ is given by,

$$s(x) = \begin{cases} 1 & \textit{if } x \le 0.05, \\ -10x + 1.5 & \textit{if } 0.05 \le x \le 0.15, \\ 0 & \textit{otherwise.} \end{cases}$$

First, we obtain the degree of (strong) agreement between individuals p and q as to their preferences between all the relevant pairs of options as

$$v_B^s(p,q) = \begin{pmatrix} 0.75 & 0.67 & 0.83 \\ & 0.75 & 0.58 \\ & & 0.67 \end{pmatrix}$$

and the degree of (strong) agreement between individuals p and q as to their preferences between Q1 ("most") relevant pairs of options as

$$v_{Q_1,B}^s(p,q) = \begin{pmatrix} 0.9 & 0.73 & 1.0 \\ & 0.9 & 0.57 \\ & & 0.40 \end{pmatrix}$$

and, therefore,

$$\text{con}_B(\text{"most"}, \text{"most"}) = 0.9.$$

If the relevances of the particular options are,

$$\begin{aligned} \mu_B(s_1) &= 0.1, \\ \mu_B(s_2) &= 1.0, \\ \mu_B(s_3) &= 0.1, \\ \mu_B(s_4) &= 1.0, \end{aligned}$$

then we obtain

$$\begin{aligned} \text{con}_B(\text{"most"}, \text{"most"}) &= 0.5998, \\ \text{con}_B^{0.9}(\text{"most"}, \text{"most"}) &= 1.0, \\ \text{con}_B^{s}(\text{"most"}, \text{"most"}) &= 1.0. \end{aligned}$$

4. An Interactive System for Consensus Reaching

In this Section we will briefly describe the structure of an interactive system for consensus reaching. We will show an example of a session concerning the choice of an investment option. The nature of the problem considered and its solution procedures imply the structure of the system, both in its hardware and software aspects. The system is shown in Figure 3.3.

The *Data Elicitation Module* makes it possible to elicit from the users, i.e. the moderator and the particular individuals, data needed by the system as, e.g., individual fuzzy preference relations, relevance of options, forms of the fuzzy linguistic quantifiers, etc. This all is possible in a user-friendly way.

The *Managing Module* is an "operating system" meant to decode the moderator's commands, the individuals' responses, etc. Basically, the *Managing Module*

(1) controls the data elicitation mode as, e.g., an initial introduction of data or their review or updating,

(2) sets appropriate parameters as, e.g., coefficients or types of algorithms for, say, computational procedures,

(3) activates an appropriate reporting facility as, e.g., display of the value of a consensus measure, or of some "troublesome" options or individuals (those causing a low value of a degree of consensus).

The *Parameter Setup Module* determines the necessary parameters and their values due to the moderator's commands decoded by the *Managing Module.*

The purpose of the *Consensus Degree Computation Module* is first of all to calculate the value of a consensus degree. The type of the algo-

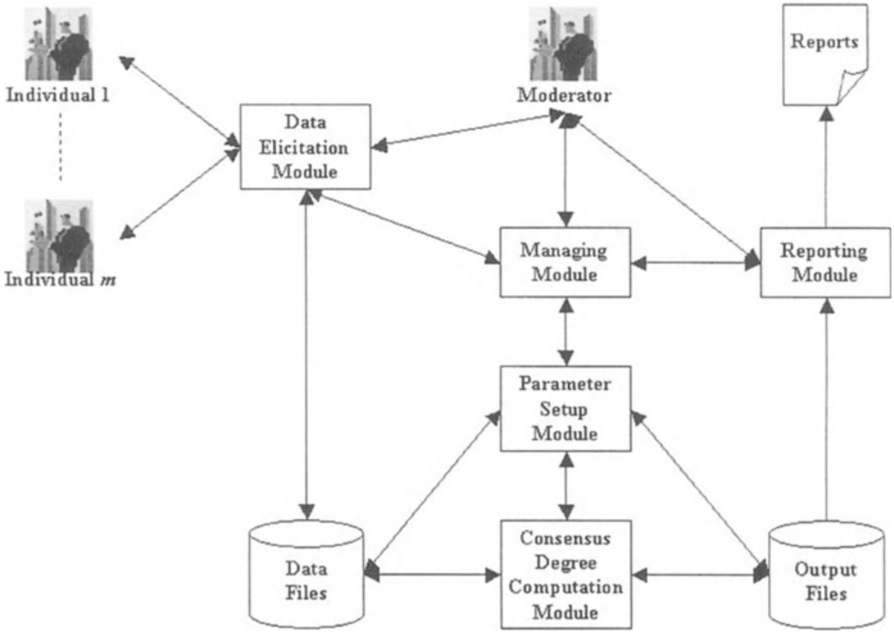


Figure 3.3. Software structure of the decision support system for consensus reaching.

rithm to be used and the necessary parameters are determined by the *Parameter Setup Module.* Moreover, the *Consensus Degree Computation Module* provides some additional information on, e.g., "troublesome" options and individuals. The *Reporting Module* provides various reporting facilities both for the moderator and the individuals, mainly concerning display of the value of a degree of consensus and its temporal evolution, "troublesome" options and individuals, "history" of changes and updates, etc.

Let us note that even we show separate terminals for the moderator and for the particular individuals in Figure 3.3, this is not a prerequisite. In the case of some hardware or software limitations, when the number of the terminals is to be limited, the system can also work fine, even in the extremal case of just one terminal for the moderator.

4.1 A Brief Description of the System

Now we will briefly present the menu-driven system, mainly in the sense of man-machine interaction. The *Main Menu* (shown in Exhibit 1) is meant for the moderator and includes basic options for initializing, running and quitting the session.

Let us sketch the essence of the particular options from the Main Menu. The "Prepare Data (Preference Matrices)" option activates the "Data Preparation Menu" shown in Exhibit 3 and briefly explained in a "help" submodule shown in Exhibit 4. The main step is to initialize the system, i.e. to introduce the fuzzy preference matrices (relations) of the particular individuals. This is explained in a "help" submodule shown in Exhibit 5. By following the instructions, one (individual one in our case) finally arrives at a fuzzy preference matrix shown in Exhibit 6. Evidently, the lower part of this matrix is irrelevant. The other options in the Main Menu (Exhibit 1) are self-explanatory. For instance, choosing options 1 or 2, i.e. "Save" or "Restore Data from Disk File", respectively, the moderator should proceed according to the "Saving/Restoring Data" help submodule shown in Exhibit 7.

The "Set Parameters" option in the Main Menu (Exhibit 1) is quite complex. It should be chosen in the beginning of each session, and less frequently during the session. By choosing this option we consecutively define the problem's parameters. First, we input the name of the problem, which is relevant for documentation purposes only, and we define the number of individuals and options (Exhibit 8).

Finally, choose the strict, sufficient or strong agreement. No parameters are needed for strict agreement. For the strong one, a function like,

$$s(x) = \begin{cases} 1 & \text{if } x \leq 0.05, \\ -10x + 1.5 & \text{if } 0.05 \leq x \leq 0.15, \\ 0 & \text{otherwise.} \end{cases}$$

should be defined. For simplicity, consider only piecewise-linear functions, defined by two boundary values.

We are now in the position to run the consensus reaching session. Choose "option 4" (Exhibit 1) to compute the degree of consensus. Then we can update the preference matrices of the particular individuals (cf. Exhibits 3 and 4). Finally, if we reach either a sufficiently high value of a degree of consensus or have no more time for the session, we quit the system. Evidently, having sufficiently similar (in terms of a degree of consensus) individual fuzzy preference relations, we can use some other known method as, e.g., given in [59-63] or [90] to pick up some option(s) which are viewed as a choice of the group of individuals as a whole. This is, however, beyond the scope of this book.

Main Menu

(1) PREPARE DATA (PREFERENCE MATRICES)

(2) SET PARAMETERS

(3) DISPLAY CURRENT VALUES OF PARAMETERS

(4) COMPUTE CONSENSUS DEGREE

(5) HELP

(6) QUIT

Exhibit 1

MODERATOR

CONSENSUS MEASURE SYSTEM

The program computes a consensus degree between opinions of a group of experts (decision-makers) as to their preferences over a set of options. Its algorithm is based on the concept of fuzzy agreement. The number of options is limited to 10 and so is the number of experts. Opinions of the experts must be expressed in the form of fuzzy preference matrices. Choose "option 1" to enter them directly from the keyboard or from the disk. There are a few parameters of the algorithm. They have default values, but you can change them. Choose "option 2" to change them. Choose "option 3" to view their setting. Choose "option 4" to start the program. During the dialog you face two forms of communication with the program: a menu and the setting of parameters.

Exhibit 2

Moderator

Data preparation menu

(1) SAVE

(2) RESTORE DATA FROM DISK

(3) ENTER/EXAMINE/CORRECT DATA

(4) CHANGE PREFERENCE MATRIX

(5) HELP

(6) BACK TO MAIN MENU

Exhibit 3

Moderator

DATA PREPARATION MENU

Now you are asked to prepare data:

- Choose "option 3" to enter data directly from the keyboard ;
- Choose "option 2" to retrive existing data;
- Choose "option 1" to save data.
- Choose "option 4" to change your preference matrix. It may be useful in the second phase of the consensus reaching process;
- Options 5 and 6 are self-explanatory.

Exhibit 4

EXPERT No. 1

HOW TO ENTER PREFERENCES

Enter your preferences as to each pair of options. The upper triangular part of your preference matrix, PRMAT, is shown on the display screen. The value of its (i, j)-th entry,

$$\mathrm{PRMAT}(i, j), i < j,$$

expresses the degree of your preference of option i over option j. The value of $\mathrm{PRMAT}(j, i)$ is obtained from the relationship,

$$\mathrm{PRMAT}(j, i) = 1 - \mathrm{PRMAT}(i, j).$$

Your preference must be expressed by one of the following numbers,

$$\{0.0, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1.0\},$$

according to the rule,

$$\mathrm{PRMAT}(i, j) = \begin{cases} 1 & \text{if option } i \text{ is definitely preferred over option } j, \\ c \in (0.5, 1) & \text{if option } i \text{ is sligthly preferred over option } j, \\ 0.5 & \text{if there is no preference (indifference)}, \\ b \in (0, 0.5) & \text{if option } j \text{ is sligthly preferred over option } i, \\ 0 & \text{if option } j \text{ is definitely preferred overoption } i, \end{cases}$$

with intermediate values for intermediate cases.

Using the cursor movement keys you can move around the matrix to modify the values entered earlier.

Exhibit 5

$$\text{EXPERT No. } 1 = \begin{pmatrix} 0.9 & 0.8 & 0.3 & 0.5 & 0.6 & 0.7 & 0.3 & 0.6 & 0.2 \\ & 0.6 & 0.7 & 0.4 & 0.1 & 0.7 & 0.8 & 0.8 & 0.4 \\ & & 0.5 & 0.3 & 0.6 & 0.7 & 0.7 & 0.3 & 0.8 \\ & & & 0.5 & 0.6 & 0.7 & 0.3 & 0.6 & 0.2 \\ & & & & 0.2 & 0.5 & 0.7 & 0.5 & 0.7 \\ & & & & & 0.5 & 0.7 & 0.6 & 0.7 \\ & & & & & & 0.8 & 0.8 & 0.4 \\ & & & & & & & 0.6 & 0.7 \\ & & & & & & & & 0.4 \end{pmatrix}$$

Exhibit 6

Moderator

SAVING/RESTORING DATA

Submit a name of the file to or from which data will be transferred. Saved or restored are the following data:

- option names
- option importance coefficients
- problem name
- number of options
- number of decision-makers (experts)
- preference matrices of all decision-makers

Exhibit 7

Moderator

ENTERING CHARACTERISTIC OF THE PROBLEM

Enter a name for the problem - this name is only for documentation purposes. The number of decision makers as well as the number of options shouldshould be between 2 and 10.

Exhibit 8

Moderator

ENTERING NAMES AND IMPORTANCE COEFFICIENTS OF THE OPTIONS

The naming of options makes it easier for the expert to enter the preference matrix.

Let us now present an example of a consensus reaching session concerning the choice of an investment option in a small community.

Example 3.2. *There are four options:*
s_1*: school,*
s_2*: movie theater,*
s_3*: shopping center,*
s_4*: swimming pool.*
There are ten individuals who represent both the local and upper level authorities, social and political organizations, some informal groups, etc. Their (initial) individual fuzzy preference relations are as follows:

$$R_1 = \begin{pmatrix} 0.9 & 0.9 & 1.0 \\ & 0.8 & 0.7 \\ & & 0.7 \end{pmatrix} R_2 = \begin{pmatrix} 0.7 & 1.0 & 1.0 \\ & 0.8 & 0.9 \\ & & 0.5 \end{pmatrix} R_3 = \begin{pmatrix} 1.0 & 0.6 & 1.0 \\ & 0.0 & 0.4 \\ & & 1.0 \end{pmatrix}$$

$$R_4 = \begin{pmatrix} 0.9 & 0.8 & 0.6 \\ & 0.6 & 0.3 \\ & & 0.3 \end{pmatrix} R_5 = \begin{pmatrix} 0.9 & 0.5 & 1.0 \\ & 0.0 & 0.4 \\ & & 1.0 \end{pmatrix} R_6 = \begin{pmatrix} 0.6 & 1.0 & 0.7 \\ & 0.0 & 0.5 \\ & & 1.0 \end{pmatrix}$$

$$R_7 = \begin{pmatrix} 1.0 & 0.7 & 1.0 \\ & 0.1 & 0.5 \\ & & 0.9 \end{pmatrix} R_8 = \begin{pmatrix} 0.6 & 0.6 & 0.4 \\ & 0.9 & 0.5 \\ & & 0.4 \end{pmatrix} R_9 = \begin{pmatrix} 1.0 & 0.6 & 1.0 \\ & 0.0 & 0.4 \\ & & 1.0 \end{pmatrix}$$

$$R_{10} = \begin{pmatrix} 0.9 & 0.8 & 0.9 \\ & 0.2 & 0.5 \\ & & 0.9 \end{pmatrix}.$$

For both the individuals and options the quantifiers (Q_1 and Q_2, respectively) are "most" given by

$$\mu_{most}(x) = \begin{cases} 1 & \textit{if } x \geq 0.8, \\ 2x - 0.6 & \textit{if } 0.3 < x < 0.8, \\ 0 & \textit{if } x \leq 0.3. \end{cases}$$

We choose the minimum t-norm and the strong agreement with

$$s(x) = \begin{cases} 1 & \textit{if } x \le 0.5, \\ -1.8x + 1.26 & \textit{if } 0.15 < x < 0.7, \\ 0 & \textit{if } x \ge 0.7. \end{cases}$$

We should note here that even for such a small example it is difficult to assess how the individuals are from consensus. To save space we will not present all intermediate steps. Let us therefore show (3.3), i.e. the degree of (strong) agreement between individuals p and q as to their preferences between all the relevant pairs of options

$$v_B^s(p,q) = \begin{pmatrix} 0.89 & 0.67 & 0.62 & 0.64 & 0.52 & 0.76 & 0.62 & 0.77 & 0.74 \\ & 0.44 & 0.61 & 0.41 & 0.41 & 0.53 & 0.68 & 0.55 & 0.53 \\ & & 0.67 & 1.00 & 0.77 & 0.98 & 0.52 & 0.94 & 0.95 \\ & & & 0.61 & 0.50 & 0.64 & 0.83 & 0.70 & 0.56 \\ & & & & 0.77 & 0.95 & 0.48 & 0.91 & 0.95 \\ & & & & & 0.71 & 0.52 & 0.70 & 0.73 \\ & & & & & & 0.47 & 0.98 & 0.97 \\ & & & & & & & 0.44 & 0.47 \\ & & & & & & & & 0.92 \end{pmatrix}$$

and (3.4), i.e. the degree of (strong) agreement between individuals p and q as to their preferences between Q_1 relevant pairs of options

$$v_{Q_1,B}^s(p,q) = \begin{pmatrix} 1.00 & 0.73 & 0.64 & 0.67 & 0.43 & 0.92 & 0.64 & 0.95 & 0.88 \\ & 0.28 & 0.61 & 0.22 & 0.22 & 0.46 & 0.76 & 0.49 & 0.46 \\ & & 0.73 & 1.00 & 0.95 & 1.00 & 0.43 & 1.00 & 1.00 \\ & & & 0.61 & 0.40 & 0.67 & 1.00 & 0.79 & 0.52 \\ & & & & 0.95 & 1.00 & 0.37 & 1.00 & 1.00 \\ & & & & & 0.82 & 0.43 & 0.79 & 0.85 \\ & & & & & & 0.34 & 1.00 & 1.00 \\ & & & & & & & 0.28 & 0.34 \\ & & & & & & & & 1.00 \end{pmatrix}$$

Assuming the same importance for all the options, i.e. $\mu_B(s_i) = 1$ *for all* $s_i \in S$, *from (3.9) we obtain,*

$$\text{con}_B^s(\text{"most"}, \text{"most"}) = 0.8069.$$

We note here that by diminishing the importance of option 3 (shopping center), we would obtain

$$\text{con}_B^s(\text{"most"}, \text{"most"}) = 0.934;$$

on the other hand, if we chose the sufficient agreement with $\alpha = 0.85$, *then we would obtain,*

$$\text{con}_B^s(\text{"most"}, \text{"most"}) = 0.0.$$

Suppose that the consensus degree, 0.8069, is viewed as unsatisfactory. A higher value of consensus can be obtained via an interaction between the moderator and the individuals. We will not present all the subsequent steps of the actual session, and we will only show some interactions whose essence might be more intuitively appealing.

In the first attempt at obtaining a higher value of a degree of consensus, as a result of the moderator's involvement there has occurred some changes in the preferences of individuals 1, 2 and 8 as to the pair of options

"2 (movie theater) - 3 (shopping center)".

Suppose that the following new values are given,

$$r_{23}^1 = r_{23}^2 = r_{23}^8 = 0.5,$$

(previously they were 0.8, 0.8 and 0.9). In this case we find,

$$\text{con}_B^s(\text{"most"}, \text{"most"}) \approx 0.9232.$$

In the second attempt, the above changes are neglected and the preferences of individuals 1, 2, 4, and 8 as to the pair

"3 (shopping center) - 4 (swimming pool)"

are changed to,

$$r_{34}^1 = 1.0, r_{34}^2 = 1.0, r_{34}^4 = 0.6, r_{34}^8 = 1.0,$$

(previously they were 0.7, 0.5, 0.3, and 0.4). Then we obtain,

$$\text{con}_B^s(\text{"most"}, \text{"most"}) \approx 0.9934.$$

In the third attempt the moderator makes the individuals accept the changes in their preferences and we get,

$$\text{con}_B^s(\text{"most"}, \text{"most"}) = 1.$$

This degree of consensus is evidently fully satisfactory, and the session is terminated.

4.2 Summary

We have presented a computer-based implementation of a decision support system for consensus reaching which is a part of an intended decision support system for supporting a large spectrum of group-decision-making-related tasks. We have used a new "soft" human-consistent degree of consensus which better reflects the real human perception of the very essence and nature of consensus. We have used fuzzy logic with linguistic quantifiers which has proved to be an efficient formal tool. Our experience shows that the system may be useful (due to its high flexibility and user-friendliness) in many practical cases.

5. The OCA Approach to Multicriteria Multiperson Consensus Modeling

In this Section we will introduce the principle of *Opinion Changing Aversion* (OCA) function and will propose an approach to consensus reaching when individual opinions are expressed linguistically.

Suppose a group of experts has to choose a preferred alternative from according to several (finite) criteria. These experts express their evaluations in a very natural way: by using a limited vocabulary of linguistic terms. Each expert is called upon to evaluate linguistically the alternatives on each of the criteria. The task of the experts is to reach some agreement during a consensus reaching process directed by a third person called the moderator. The experts are expected subsequently to change their testimonies - via mutual interactions such as exchange of information, negotiation, bargaining, etc., and perhaps with help from the moderator - until sufficient agreement (consensus) has been reached.

The measure of consensus depends on a function estimated for each expert according to his/her aversion to opinion change.

Let us assume that a group of experts has either to choose a preferred alternative from a set of admissible ones or to give a ranking to the set of alternatives, both operations according to several explicit criteria. In formal terms, we have the following sets,

- admissible alternatives: $A = \{A_1, A_2, \ldots, A_N\}$,
- judgement criteria: $C = \{C_1, C_2, \ldots, C_M\}$,
- experts consulted: $E = \{E_1, E_2, \ldots, E_K\}$.

The experts can express their opinions in a natural way, since the system provides them with a limited vocabulary of linguistic terms. That is, the experts can choose a linguistic label from a term set V, the range of which is pre-established. For example,

$$V = \{\text{very low, low, medium, high, very high}\}.$$

Thus each expert is called upon to evaluate the decision alternatives in terms of their *performance* with respect to each criterion. These performances can be expressed in a matrix form (see Table 3.1). The elements of these matrices are called the *linguistic performances* of the alternatives on the criteria.

Table 3.1. A matrix of linguistic performances.

	C_1	C_2	...	C_j	...	C_M
A_1	high	very low		...		low
A_2	low	low		...		medium
...						
A_i	high	medium		...		medium
...						
A_N	very high	low		...		low

At the beginning of the session we determine the semantics of the terms in the vocabulary i.e., the meaning of *high*, *medium*, etc. The values of V are represented by *fuzzy numbers* of trapezoidal type, defined by the following quadruples,

$$\mu_{ij}^k = \left(\alpha_{ij}^k, \beta_{ij}^k, \gamma_{ij}^k, \delta_{ij}^k\right) \tag{3.10}$$

for $i = 1, \ldots, N$, $j = 1, \ldots, M$ and $k = 1, \ldots, K$.

These fuzzy numbers are able to capture the fuzzy uncertainties of human intuition. Much has been written in the literature about the use of fuzzy numbers. However, most authors acknowledge that they are particularly useful in those situations in which probability or utility values cannot be precisely defined but are obtained through verbal statements ([25,27]).

5.1 Aggregation and Linguistic Approximation

We subsequently perform some classic steps in aggregation [109] and linguistic approximation [28], in order to evaluate an overall linguistic value of performance for each alternative and for each expert; that is, the overall performance obtained for each expert when all the criteria are taken into account.

As a first step we must solve a multi-criteria ranking problem for each expert. In similar situations in the literature, this problem has been resolved using different approaches. One of the methods most frequently used is the so-called fuzzy outranking relation characterized by a degree of credibility which depends on two other indexes: a confidence index and a doubt index.

The method we propose is closer to the one suggested by R. M. Tong and P. Bonissone [109,10] who present a multi-choice model based on fuzzy information expressed linguistically. This model aggregates the linguistic performance values assigned to each alternative.

We proceed in two stages. First, we compute an average, maybe a weighted one, for the performance values. Then we solve the problem of *linguistic approximation.* The weighted average of the linguistic performance values is calculated for each alternative and each expert as follows:

$$\mu_i^k = \left(\frac{1}{M} \sum_{j=1}^{M} \pi_j^k \alpha_{ij}^k, \frac{1}{M} \sum_{j=1}^{M} \pi_j^k \beta_{ij}^k, \frac{1}{M} \sum_{j=1}^{M} \pi_j^k \gamma_{ij}^k, \frac{1}{M} \sum_{j=1}^{M} \pi_j^k \delta_{ij}^k \right),$$

where,

$$w_j^k = \frac{\pi_j^k}{\sum_{j=1}^{M} \pi_j^k},$$

with π_j^k = weight assigned to criterion j by expert k.

The result of the aggregation must be translated back into linguistic terms. In fact, the fuzzy numbers obtained in the previous aggregation phase usually do not correspond exactly to terms in the initial vocabulary. We must therefore identify one term of the linguistic vocabulary and associate it with each fuzzy set of the matrix previously computed. That is, we inspect the term set and choose the linguistic label the meaning of which comes closest to the meaning of each fuzzy set corresponding to the overall performance of the alternatives.

When we have trapezoidal membership functions, the quadruples

$$(\alpha, \beta, \gamma, \delta)$$

produce a complete representation of the fuzzy set. In order to select a label for these fuzzy sets we use the distance defined in terms of

$$d(V_l, \mu_i^k) = \sqrt{P_1^2(\alpha_l - \alpha_i)^2 + P_2^2(\beta_l - \beta_i)^2 + P_3^2(\gamma_l - \gamma_i)^2 + P_4^2(\delta_l - \delta_i)^2}$$

where $V_l = (\alpha_l, \beta_l, \gamma_l, \delta_l) \in V$ and $\mu_i^k = (\alpha_i^k, \beta_i^k, \gamma_i^k, \delta_i^k)$. Furthermore, P_1, P_2, P_3, P_4 denote the importance of $\alpha, \beta, \gamma, \delta$ in representing a fuzzy set. We choose the V_l^* from the relationship

$$d(V_l^*, \mu_i^k) \leq d(V_l, \mu_i^k) \quad \forall V_l \in V, \ (|V| = L < \infty).$$

Information available after the process of linguistic approximation is represented by a bidimensional matrix $N \cdot K$ where the element in position (i, k) is the trapezoidal label of the overall linguistic value of performance attributed by the expert E_k to alternative A_i.

5.2 The Session for Consensus Reaching

The group of experts could be depicted as a black box that receives information about the problem (input) and should give a satisfactory solution (output). First of all, a suitable representation is given to the decision problem (i.e. the possible solutions or alternatives and evaluation factors for criteria). Then the input data, i.e. the experts' individual opinions, is gathered (performances of alternatives with respect to each criteria).

After processing the initial data (aggregation and linguistic approximation), a *consensus degree* on each alternative is evaluated. If consensus is reached, we finish the session successfully. Otherwise some of the opinions given by the experts need to be changed. In other words, if there are alternatives on which agreement has not been reached, the moderator - who could theoretically be one of the modules of the SW system - invites the experts to modify their positions, taking into account their aversion to opinion change.

The model offers various criteria in order to identify some consensus strategies and manages the consensus reaching process without enforcement. This is carried out by letting the experts know how they should change their opinions in order to increase the degree of consensus. In this sense, the negotiation process also involves learning. The logical architecture of the proposed model is depicted in Fig. 3.4.

The graph in Fig. 3.4 shows that there are two feedback levels: one as global evaluation, and the other as input values. In reality it would be necessary to consider a third feedback level, on the parameters of the problems, that is, on the generation of the alternatives (problem restructuring, [99]). Summing up these findings, three phases can be recognized in the decision process,

- Problem Representation.
- Data Input and Evaluation of Group Opinion.
- Consensus Evaluation and Changing of Opinions.

Compared to the model proposed in [21], these three components correspond respectively to *Input*, *Conflict Interaction Process* and *Output*.

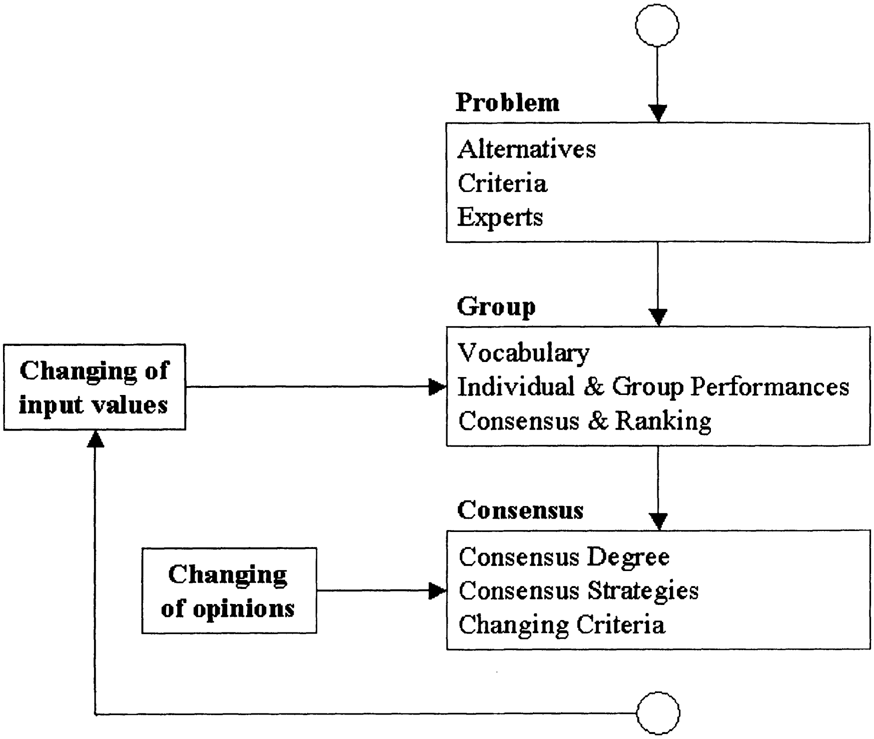


Figure 3.4. The logical architecture of the proposed model.

After the aggregation and approximation stages, one may establish the ranking of the alternatives for each expert by using one of the many algorithms proposed in the literature (see, e.g., [12,96]).

The last and fundamental problem to be solved is determining a *consensual ranking.* We propose a fuzzy-logic-based approach that works well without any particular hypothesis about the behaviour or rationality of the experts (unlike models that are based on preference relations and utility concept).

Assuming that all alternatives are independent we compute the consensus degree for each alternative as the weighted average of the linguistic performance values of each expert. The consensus level required for each alternative is fixed in advance as a percent of dispersion of the experts' linguistic performance values. If consensus has been reached for all the alternatives, the session for the consensus reaching can be closed. If this does not happen, the experts' opinions must be modified.

In our model the process of modifying opinions is managed by introducing the concept of opinion changing aversion (OCA). That is, we define for each expert a function representing his/her resistance to opinion changing. For the k-th expert this function has the following form,

$$f_k(x|V_k^*) = 1 - \frac{2}{e^{\frac{x-m_k}{a_k}} + e^{\frac{-x+m_k}{b_k}}},$$

where x takes its values from the set M, whisch denotes the the defuzzified values of performances given by the experts, and m_k is the defuzzified value of V_k^*. The defuzzification method we use is the center-of-area method (for other defyuzzification methods see [40,45,95]).

Now we have to find a strategy for each non-consensual alternative, which modifies the opinions of the experts in order to obtain a new set of individual performance values whose weighted mean is closer to the *consensual label.* The strategy chosen will be the tuple $(V_{k_1}, V_{k_2}, \ldots, V_{k_K})$ that minimizes the overall aversion to opinion change.

We define the consensus degree, relative to alternative A_i, as a function both of the standard deviation (s_i) of the sequence of linguistic performance values of the experts and of the range (r_i) of the linguistic values V_l, over the universe of discourse V. Formally, we have,

$$s_i = \left(\frac{1}{K-1} \sum_{k=1}^{K} [d(V_k^*, \mu_i)]^2 \right)^{1/2},$$

where μ_i is the linguistic mean of the experts' performance values. The range will be

$$r_i = \max_j\{\beta_j\} - \min_j\{\alpha_j\},$$

normalizing we obtain

$$\sigma_i = \frac{s_i}{r_i},$$

and then the consensus degree is defined as follows

$$\text{con}_i = 1 - \sigma_i.$$

The problem to solve now is to select from all strategies, compatible with a fixed desidered consensus label, that one minimizing the overall aversion to opinion change. From a formal point of view we have:

$$\min \sum_{k=1}^{K} f_k(x|V_l^*), \text{ subject to } \text{con}_i \geq \tau_i,\ x \in M, \tag{3.11}$$

where τ_i is the minimum admissible consensus level, fixed in advance.

The moderator now invites the experts to shift their opinions towards the consensual label according to the optimal strategy

$$(\widehat{V}_{k_1}, \widehat{V}_{k_2}, \ldots, \widehat{V}_{k_K}).$$

After the experts have changed their opinions, the new degree of consensus is computed and if it is greater than or equal to the minimum admissible level the process stops. Otherwise the parameters of the program (3.11) are updated and a new solution is looked for.

The interactive and iterative process will finish when for each alternative the minimum level of consensus or a deadlock is reached.

6. Quality Evaluation of Elderly Persons' Homes Using Fuzzy Quantifiers

The quality of services offered by *Elderly Persons' Homes* should be measured regularly. This mesurement requires up-to-date and complete information, organized in a way that precise evaluation can be carried out by typical decision support tools.

In our project[1] we have considered a primary need to create a scheme for a global evaluation of the residential structures and their services, so as to improve the standard of life of these people.

From this point of view, we need to verify the actual needs of the guests of the *Elderly Persons' Homes*, to evaluate the services they offer and to study how these people adapt to a new type of life. All this can't be left to single institutes, but has to be accomplished within a clear programmatic framework, which allows to carry out effective choices starting from clear and precise information.

The nature of the problem is such that many pieces of relevant information are subjective, that is to say they are evaluations expressed in most cases in linguistic forms from those who are designated as experts in that particular field. Therefore the most appropriate representation tools for such type of information are the linguistic variables. First we define the most appropriate scheme representing the information concerning "Elderly Persons' Homes".

To such an extent we identified a set of attributes, whose evaluation, in linguistic terms, has been carried out by a group of experts. Each expert has chosen, among the performance judgements available within the questionnaire, the one which he considered the most appropriate. As an example, let's consider the evaluations of the bedrooms' condition. They are organized into four types,

[1] "Protective measures for old people's health", promoted by the *Social Service Department of the Regional Government of Trentino, Italy.*

I. Bedrooms for self-sufficient guests (with a single bed).

II. Bedrooms for self-sufficient guests (with more than one beds).

III. Bedrooms for non self-sufficient guests (with a single beds).

IV. Bedrooms for non self-sufficient guests (with more than one bed).

Each type is represented by a vector of fuzzy quantifiers, represented by L-R fuzzy numbers [99]. These L-R fuzzy numbers have been chosen of triangular shape. and they make it possible to express evaluations in the natural language, which is typical for the very experts in the field, who usually know the numeric scales and their transformations only superficially. It should be noted that the attribute evaluation phase must be preceded by a session during which the experts of the problem and the experts of the methodology cooperate to estimate the membership functions. Coming back to the case studies, each element of each class has been treated like an attribute. Therefore the generic "bedroom for self-sufficient guests" (more than one bed), relative to the Elderly Persons' Homes marked with code x, has been given the following representation:

$$SSMb_V(x) = (v_1, v_2, v_3, v_4, v_5, v_6).$$

In the questionnaire n has been placed equal to six, and more precisely:

v_1: cleanliness
v_2: furniture
v_3: room arrangement
v_4: lighting
v_5: order
v_6: overcrowding

An expert evaluating "cleanliness", has a universe of discourse,

$$\text{U} = \{\text{poor, fairly good, good }\},$$

but this vocabulary can be broaden upon his wishes to include other terms (for example adjectives, in order to create variations in this basic fuzzy set).

The semantic of each element in U is a fuzzy set, defined within the interval [0, 1]. The SSMb(x) habitability has thus been computed by aggregating the values assigned to v_1, v_2, v_3, v_4, v_5, v_6 respectively [26]. The choice of the most suitable operators undergoes crossed evaluations by the experts; in the system proposed here such a choice mechanism has been set. The aggregation makes it possible to quantify the answer to questions like:

"Which is the degree of habitability of a room if the cleanliness is good, the order is good, the furniture is good, the room arrangement is poor, the lighting is fairly good and the overcrowding is acceptable?"
or other questions of the same type. The use of the fuzzy set algebra has similarly allowed to obtain an overall evaluation of the rooms' habitability.

Working in a similar way for all the other attributes, we are able to describe Elderly Persons' Homes through the following vector,

$$(x_1, x_2, \ldots, x_n),$$

where, x_1 denotes the habitability of bedrooms, x_2 stands for the efficiency of clinical bathrooms, x_3 evaluates the functionality of kitchens, etc.

The overall evaluation of the quality of the service offered by each house is computed by aggregating the fuzzy values used for evaluating x_1, x_2, x_3, etc. We assume that the attributes can have different importances of linguistic form. Thus, having indicated the operators chosen through $*$ and $\circ$ (e.g., OWA or MICA) [114], and the weights associated to the attributes with p_1, p_2, $\ldots$, p_k, the quality of the service offered by the house x is computed in the following way,

$$q(x_1, \ldots, x_k) = p_1 * x_1 \circ p_2 * x_2 \circ \cdots \circ p_k * x_k.$$

At this stage two algorithms of calculus have been proposed. The first one - which makes it possible to rank the Elderly Persons' Homes according to the quality of the service offered - is based on the extended maximum (for a complete review see [26]).

The second one - which determines the consensus degree among the experts when evaluating the overall quality of each Elderly Persons' Homes - applies the model proposed in [52], which is based on fuzzy logic and linguistic quantifiers. The second algorithm should be applied when the overall evaluations - set by the single experts in a totally autonomous way - disagree with those computed by the system itself. To facilitate the comprehension of the results obtained, we have decided to adopt graphic representations.

This fact makes it possible that users not particularly comfortable with fuzzy sets (and not very familiar with their numeric representation) can easily interpret the conclusions deriving from such processing.

The following pages report the outcomes obtained by taking into account both the whole set of the attributes - the overall evaluations - and the clusters which are considered more meaningful.

More specifically, they are: the habitability (evaluated only on the basis of all the attributes concerning the bedrooms, both for self-sufficient guests and not), the hygienic/sanitary situation (estimated inspecting the attributes relating to the hygienic/sanitary services, clinical toilettes, etc.) and the situation of the toilettes/living rooms (evaluated by taking into account all the attributes concerning the dining-rooms and the living-rooms, the kitchens, etc.).

On the other hand we do not consider important the investigation of all the remaining attributes (the laundries, the accessibility, the stairs, etc.), which are not "discriminating". The conclusions obtained have been represented with three different kinds of graphs, and more precisely:

- **Histograms**: provide a quantitatively "weighted" representation of the evaluation as to the various Elderly Persons' Homes or as to the attributes (with reference to all the Houses). The upper positions of the columns are directly proportional to the quality. They can evaluate the "distances" among the various entities or attributes, and therefore can appreciate better the relevance of their position within the graduation. They can learn when the difference between the last positions is bigger than the difference we find between the first ones or between the middle positions - showing a sharp worsening for the most backward Homes or services - as well as the opposite - generally representing a mediocre evaluation when there are only few advanced points.

- **Dendrograms**: visualize the associations among the Homes according to the attributes which are more similar comparatively. They provide a hierarchical qualitative representation of the characteristics of the Homes, which are ranked either according to the overall set of attributes or using those clusters considered more meaningful. The diagram can be read as an evaluation of the "difference" among the various Homes, where greater differences among the attributes imply a corresponding gap within the graph (the "distance" among the various Homes can be evaluated through the length of the branches of the gerarchic tree).

- **Dispersion Maps**: rank the considered item - within a spectrum of values ranging from "totally inacceptable service" (0), to "absolutely perfect service" (1) - based either on all the attributes or different types of aggregation.

  They can represent the quality of each Home (the evaluation of the quality is based on the reliability of the relevant attributes) or of the different attributes. In this case they allow us a visual evaluation both of the quality of the services supplied and the conditions of the different Homes, without neglecting the differences, also relevant, among the different attributes or Homes (attributes or Homes which are close to each other in the map are also similar from the point of view of the quality supplied either by the service or by the Home).

The upper right side shows the excellence, while the lower left side shows the worst conditions. Along the diagonal sloping down from the upper left corner to the lower right, there stands the mediocrity. Therefore, this representation can provide a qualitative evaluation of the aggregations.

In our analysis the "non discriminating" attributes have not been considered. Over 93 attributes have been evaluated, (the "Juridical Nature" has been taken into account only for explanatory purposes), from which the following 17 attributes have been crucial,

7. Bedroom for self-sufficient guests (single bed) - overcrowding,
11. Bedroom for self-sufficient guests (more than one bed) - lighting,
43. Floor dining-room - cleanliness,
46. Floor dining-room - lightness,
49. Floor dining-room - accessibility,
50. Floor living- room - cleanliness,
57. Floor kitchen - cleanliness,
62. Lift (the second one),
63. Lift (the third one),
64. Lift used for stretchers (the first one),
65. Lift used for stretchers (the second one),
66. Common dining-room - cleanliness,
69. Common dining-room - lightness,
72. Common dining-room - accessibility,
73. Common living-room - cleanliness,
79. Common living-room - accessibility,
80. Kitchen - cleanliness.

7. A Decision Support System for Strategic Planning Through Scenarios

In this Section we will describe a decision support system for strategic analysis and planning, which is based on the *scenario method.* The system, developed for a multinational company, helps the decision makers to get synthetic information out of a formal representation of scenarios describing the complex network of relations between the strategic variables for the company.

The representation of the scenario through cognitive maps makes it easier to develop, update and search for information within the model, and allows sophisticated processing and graphic representation. Starting from some qualitative evaluations on the importance of variables and scenario relations, the system computes syntethic indicators expressed in a linguistic way by applying the fuzzy logic concepts. A group decision environment is characterised by a set of experts who are called to express their judgements on a set of alternatives with respect to a predefined set of criteria, in order to select the best one(s).

The objective is to evaluate a consensual judgement and a consensus degree on each alternative; as the main "actors" in a group decision activity are individuals with their own subjectivity, the models based on linguistic approaches are particularly appealing. Assuming that the experts are seriously committed to consensus, they are subsequently expected to change their testimonies until sufficient agreement (consensus) has been reached.

When considering the framework of today's enterprises, essentially characterised by quick changes and increasing uncertainty resulting from the dynamics of the social and economic environment, analysis and planning, beside the analysis of environmental trends, play a central role. The purpose of the scenario analysis is to conceive all possible futures, by taking into account the interdependence and mutual relationships, which enables companies to move from prospective reflection to strategic action.

7.1 Predictions and Scenarios: Problems and Methods of Creation

A prediction is a priori statement about an event; it has developed as an effective tool to support strategic analysis and planning through a complex of methodologies and technologies called scenario [85]. The scenario method is designed to describe the future (or all alternative possible futures) by identifying key variables and the structure of the relationships between them, mixing interdisciplinary approaches: management science, decision theory, cognitive science, artificial intelligence, etc. We will discuss external or environmental predictions. Scenarios can be classified as follows [86],

- descriptive scenarios, which provide insights into cause and effects relationships;
- normative scenarios, which explain how to achieve a set goal.

Along with descriptive and normative scenarios, we can define "mixed scenarios", that combine features of both types. As to temporal dimension we distinguish between trend-based scenarios and anticipatory ones. These definitions provide a syntesis of future events.

Past events should be carefully evaluated. Many people claim that under uncertainty there is no theoretical foundation to make predictions about future trends. Another basic point relates to people who make predictions and their ability to elaborate accurate predictions, which tend to highlight new aspects of possible futures. Sometimes it appears to be better if scenarios are analyzed by groups, maybe with the help of external experts; this seems to be one of the best solutions to problems related to framing, especially if prediction is purely based on intuition. Scenarios may vary according to the time span involved in a prediction.

Furthermore the analysis takes into account not only the quantified or quantifiable data, but also qualitative parameters. Building scenarios integrates economic variables with political, technological and social factors, which can exercise significant influence on the development of the system.

Now we will present a decision support system which applies to a scenario structure, an integration which can potentially enhance and improve the quality and efficiency of strategic planning and analysis. The variables of the system should be identified by the following factors,

- Variables' relevance in the context of the scenario.
- The way they are expected to happen.
- Identification of cause-effect relationships between them.

There are two kinds of major variables that provide a better understanding of the structure of the system,

- Exogenous variables, defined by external factors; (they offer a synthesis of these external factors).
- Other variables that represent the outcome of the combination of a series of events.

Variables of the third tyoe are the so-called mixed vriables: possible future states are described using both cause-effect relationships and the way these variables may develop. The DSS aims at providing tools for representing and understanding why an event will be the true future state in a cause-effect network.

This structure allows us to identify causes of uncertain events and to determine a chain of effects linked to their fulfillment. In this structure we can identify sequences of causal connections, which may amplify apparently marginal events, that nobody conceived before.

This may orientate us towards the investigation of weak signals, that could become very influential and anticipate the evolution of events, and towards the research of multiplicative effects, identified by circular sequences of variables interconnected by cause-effect relationships (loops).

We shall present a decision support system that performs some scenario analysis and can construct alternative scenarios.

7.2 Network Patterns for Knowledge Representation

The proposed decision support system can be represented by a set of nodes (relevant concepts for the final decision, i.e. decision variables), interconnected through arcs (causal relationships among the concepts). Thus we obtain a network of nodes linked by arrows (sometimes called "influence diagram"). In this way we have a formal representation of information about the problem; the decision-maker, starting from known concepts, or a concept he is able to evaluate in a limited period of time (with a sufficient accuracy) (*input nodes*), can follow the reasoning along such a network, until reaching some conclusions (*output nodes*), which logically derive from the stated premises (*causal reasoning*). Backward chaining (from conclusions to premises) is also possible (*evidential reasoning*). Usually, scenarios, represented by graphs, should satisfy the following properties,

- Oriented (or directed): the causal relations are represented as arcs from the cause variable to the effect variable, therefore the pair (i, j) is ordinate.
- Simple: there is a single arc between two nodes.
- Weighted: each node has a weight (interpreted as the absolute relevance of the variable), and each arc has a weight (causal relation relevance).

These graphs can be represented by the following quintuple,

$$G(N, A, V, R, S)$$

where V, R and S are functions, such that V associates with each variable i (node) a weight v_i, R associates with each relation (arc)(i, j) a weight $r_{i,j}$, and S associates to each relation (arc) a sign $s_{i,j}$ $\{+, -\}$, and $G'(N, A)$ is a graph. A plus sign is attached to the arcs that show direct relationships, and a minus sign is used to indicate indirect relationships.

The decision makers can formulate their judgements on v_i and $r_{i,j}$ in a natural way, using a limited set, S, of seven linguistic terms. The elements of the scale S are the following,

S = {Very Low (VL), Low (L), Rather Low (RL), Medium (M), Rather High (RH), High (H), Very High (VH)}.

Following Zadeh's approach, we will represent the linguistic terms by fuzzy numbers. The graph has the following properties,

- Weakly connected: regardless the orientation of the arcs, always exists at least one step-path between each pair of nodes in the graph.
- Cyclical: moving along any path following the orientation of the arcs, you can return to a node already visited.

An elementary path w_{ij} is any subgraph of G defined by a "parent variable" i, a "child variable" j, and the connection between them (i, j). The linguistic variable $w_{i,j} = \phi(v_i, v_j, r_{i,j})$ is called relevance of the elementary path $W_{i,j}$, and it represents the importance of the elementary path linking i and j.

Retrieving synthetic information from such a complex model appears to be a really hard task for human decision makers. A system supporting strategic analysis and planning has to process this model to point out cause-effect relationships, which help and improve decision maker's evaluation of possible alternative futures. Statements on decision variables are generally too vague, uncertain and imprecise to be suitable to description in conventional crisp numerical values. Therefore the use of fuzzy logic appears natural for managing the scenario problem [71]. The first step in obtaining synthesis data from scenarios is to calculate the relevance of an elementary path.

To overcome this problem we define a heuristic for each triple of linguistic labels

$$(v_i, v_j, r_{i,j}) \in \{VL, L, RL, M, RH, H, VH\},$$

representing the result of their aggregation. Since we have $7^3 = 343$ possible triples, it is worth building an heuristic translating the linguistic terms into numbers {1, 2, 3, 4, 5, 6, 7}, and applying the algorithm decsribed in Table 3.2.

To get synthetic information from scenarios, we need to revisit the graph and calculate the desired indexes. Each graph $G(N, A, V, R, S)$ is saved as a list of adjacencies (see Table 3.3).

Furst we apply the Depth-First algorithm, which involves expanding time after time one of the layers generated during the immediately previous move [42]. As to the standard Depth-First algorithm, we introduce two important changes,

- Loop management: using the standard algorithm with cycles the program gets in a loop, therefore at each step the procedure must control that the state which is about to expand hasn't been reached yet.

Table 3.2. A heuristic translation of linguistic terms into natural numbers.

ADDITION = $v_i + v_j + r_{i,j}$	
CASE	addition ≤ 6
	Relevance = Very Low
CASE	addition ≥ 7 AND ≤ 9
	Relevance = Low
CASE	addition ≥ 10 AND ≤ 11
	Relevance = Rather Low
CASE	addition = 12
	Relevance = Medium
CASE	addition ≥ 13 AND ≤ 14
	Relevance = Rather High
CASE	addition ≥ 15 AND ≤ 17
	Relevance = High
CASE	addition ≥ 18 AND ≤ 21
	Relevance = Very High

Table 3.3. A sample from the list of adjacencies.

NODE	WEIGHT	CONNECTED TO	SIGN	WITH WEIGHT
1	Low	5, 7, 14	+, -, +	L, H, VH
2	Very High	3, 12, 22	+, +, +	M, M, VH
...	...	...	...	...

- Weak connection management: to move along a low relevance elementary path is not rewarding. Furthermore, whereas the number of nodes and connections grow, the Depth-First efficiency rapidly declines, so that it is convenient to make use of some devices reducing computations.

For this reason the program cuts off the path which we are going through, if w_{ij} is less than a linguistic threshold, fixed in advance. The modified algorithm is described in Table 3.4. The list comprises the nodes which are about to be expanded, the closed list those already expanded.

Table 3.4. The Depth-First algorithm for managing loops and weak connections.

0.	empty the opened and closed lists
1.	insert the starting node into the opened list
2.	IF the opened list contains no more nodes THEN stop: the visit is finished
3.	IF the first node within the opened list has no "child" OR exists within the closed list OR W_{ij} is a weak connection THEN remove it from the opened list OTHERWISE 3a. instead of the first node of the opened list insert its "children" 3.b insert the node just removed from the opened list into the closed one
4.	go back to step 2

7.3 Structural Analysis

Structural analysis is a static tool which attempts to establish the role of a variable or of a casual chain within the scenario system. To perform such a task, two indicators are defined,

- The relative relevance of a variable, which is an indicator of the potential capability to influence other relevant variables. The result shows all the variables of the scenario ordered using this indicator.
- The relevance of a causal chain arising from a certain variable. The result of this process presents all the casual chains starting from a certain variable, which are ranked according to this indicator.

  The construction of the first indicator is based on the following assumption: the more important the variables and connections belonging to sub-graph T_i , which is formed by all the variables descending from the variable i, the more important the variable i itself. It comprises two stages,

- Individuation of the sub-graph T_i by means of the algorithm described above.
- Aggregation of the values coming out from each elementary path which belongs to subgraph T_i .

This aggregation is performed by using the *Weighted Median Aggregator* (WMA) introduced by Yager [116], which makes it possible to compute the median of non-numeric sets, whose elements are ordered and weighted by non-numeric and ordered elements.

Let us assume that the nodes forming the subgraph T_i are the elements to be aggregated, and the arcs getting into them are the weights associated to the nodes. Since the central elements play a crucial role in median computation, the WMA procedure implies that all the minor elements are not to be in the centre, and that each one of them is to be substituted by elements which are close to the two extremes that neutralize reciprocally.

In this way we compute w_i, an indicator of the relative relevance of variable i, just making use of ordinal scales. Another formalization have been proposed, dealing with the weights of nodes and arcs evaluated on a cardinal scale.

A feasible indicator of the relative relevance of variable i is given by the arithmetic mean of the mode of the fuzzy numbers representing the linguistic evaluation of the elementary paths we have followed,

$$w_i = \frac{\sum\limits_{\{i,j\} \in T_i} w_{ij}}{|T_i|},$$

where $|T_i|$ is the number of elementary paths contained in T_i.

The program also contains a dispersion indicator for a more complete w_i interpretation. If this calculation is carried out for each node of the graph, we can rank the variables according to their relevance.

It may be worth evaluating the more important causal chains starting from a given variable. For such a purpose we assumed that the more important the variables and connections within certain causal chain, the more important the chain itself. The construction of this indicator involves two stages,

- Individuation of the casual chains arising from node i by visiting the graph through the previously described visiting alghoritm.
- Aggregation of the values resulting from each elementary path belonging to each causal chain.

In order to define the relevance of a causal chain k starting from node i, $c_{i,k}$, we can point out two different approaches. The first one obtains such an indicator by applying the WMA on the weights of nodes and arcs belonging to causal chain k. The second approach works by introducing a cardinal scale for the set of weights associated with the nodes and the arcs; $c_{i,k}$ is thus obtained by computing the arithmetic mean of the model of the fuzzy numbers representing the linguistic evaluation of the elementary paths visited.

$$c_{i,k} = \frac{\sum\limits_{\{i,j\} \in C_{i,k}} w_{ij}}{|C_{i,k}|},$$

where $|C_{i,k}|$ is the number of elementary paths contained in $C_{i,k}$.

Again, the program contains a dispersion indicator for a more complete interpretation of $c_{i,k}$. Processing the same calculation for each causal chain starting from node i, it is possible to arrange a rank of the casual chains according to their relevance.

Table 3.5 contains all the linguistic indicators proposed in our approach.

Table 3.5. Linguistic indicators.

Indicator	Symbol	Definition
Absolute relevance of i	v_i	decision makers' judgement on the weight of the variable i
Relevance of connection (i,j)	$v_{i,j}$	decision makers' judgement onthe weight of the connection (i,j)
Relevance of $W_{i,j}$	$w_{i,j}$	heuristic described above
Relative relevance of i	w_i	$w_i = \text{WMA}(v_1, r_{1,2}, v_2, r_{2,3} \ldots)$ or $w_i = \frac{\sum_{i,j} w_{ij}}{\lvert T_i \rvert}$, $(i,j) \in T_i$
Relevance of the k-th causal chain starting from node i	$c_{i,k}$	$c_{i,k} = \text{WMA}(v_1, r_{1,2}, v_2, r_{2,3} \ldots)$ or $c_{i,k} = \frac{\sum_{i,j} w_{ij}}{\lvert C_{i,k} \rvert}$, $(i,j) \in C_{i,k}$

7.4 Summary

The approach persented in this Section provides a valuable support in controlling a high number of variables and their relationships. If we have a knowledge representation problem with a high degree of complexity, it may be interesting to describe the possible alternative futures using more sub-scenarios into which we can decompose the main scenario.

To such an extent we detect the key variables and identify a network of their causal relationships in two different ways: a synthetic scenario describing all the relationships between the key variables, and sub-scenarios for all the other variables. This process could help the decision maker to enrich the predictions with informative elements. We could also consider time dimension when structuring the relations within variables. It is certainly true that some cause-effect relationships may be more or less delayed in time; what we generally mean by relevance does not include this idea, and this brings us, in certain cases, to overestimate or underestimate the diffusion of the effects of the changing status of the variables.

8. An Artificial Neural Network Evaluator for Mortgage Loan Applications

In this Section we present the structure of an artificial neural network designed for evaluation of mortgage loan applications [82] in the housing business. Its purpose is to support the decision maker specialized in analysing loan applications, providing him with a pre-estimate as a reference point, in accordance with the historical experience of the bank in this sector. The system has been created *to support* and *not to replace* the decision maker, who is authorized to take the final decision about the applications.

Based on a neural network learning mechanism from training examples, the system can emulate the implicit evaluation criteria in the historical experiences of two banks, according to three possible ways: the first bank evaluation (based on 200 examples, of which 86 cases are real and 114 virtual), the second bank evaluation (just as before), and their joined evaluation, based on the 400 total examples.

Each training example consists of an application pattern, characterized by 16 input variables, and the corresponding evaluation, expressed by a single output variable from the unit interval, where zero denotes *loan refusal* and one denotes *loan approval.*

After the training process the neural network evaluator can evaluate new mortgage loan applications. The system can carry out a mechanism for sensitivity analysis for each new mortgage loan application and can highlight the most critical input variables.

The neural network evaluator requires the mortgage loan application to meet some preliminary filters tested directly by the decision maker, and these filters themselves can exclude the loan concession. These filters are,

- A preliminary check on the client: civil status, family status, statements of assets and liabilities, positive (or at least not negative) evalu-

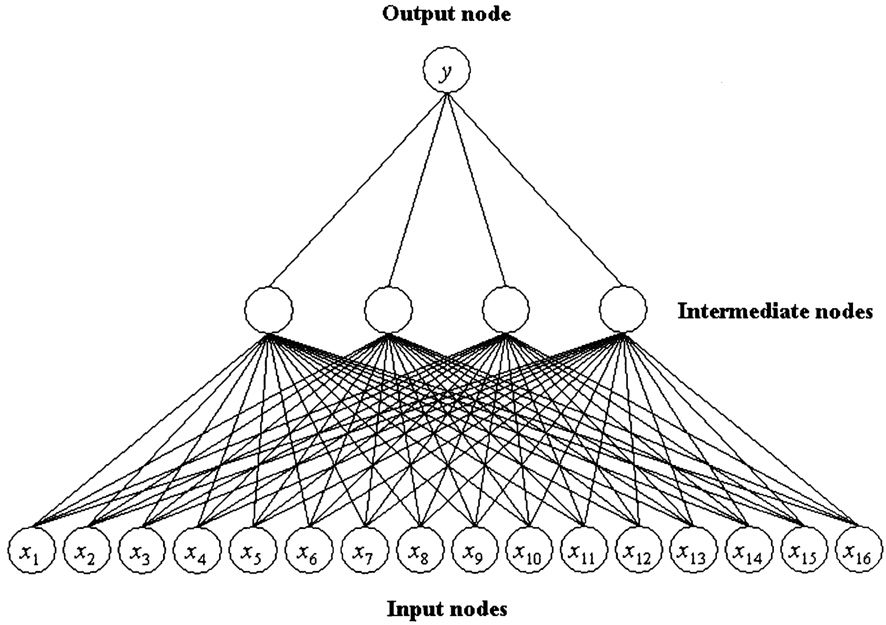


Figure 3.5. The architecture of neural network evaluator.

ation of the past relationships between the client and the bank, which is carried out both in general and particularly in cases of funding.

- A preliminary check on the real estate: land registration and/or ipocadastral status of the estate (occupancy, mortgages, usufructs), compatibility between the cost of the real estate and the value determined by an expert's appraisal, amount of money required for the loan, which cannot be higher than 80% of the value established by an estimate.

In the following we will describe the components of the neural network evaluator.

The neural evaluator processes the information given by 16 input variables, which provide a comprehensive picture of a mortgage loan application. The first four inputs (1-4) describe the financial plan associated with the loan application, while inputs 5 and 6 specify its respective amortization plan. The following six inputs (7-12) concern the income and the estate both of the applicant and the guarantee; the last two inputs (11-12) express evaluations on the quality of the relationships between the applicant and the bank.

Quantitative inputs are expressed in a numeric form, whereas qualitative ones are represented by fuzzy numbers. In the following list of input variables, the term "transactions" means purchase and/or restoration of a real estate.

1. Requirements: Cost of the Real Estate (quantitative variable)
2. Requirements: Accessory Costs (quantitative variable)
3. Covering: Own Resources (quantitative variable)
4. Covering: Loan Request (quantitative variable)
5. Loan Request: Duration (quantitative variable)
6. Loan Request: Installment, with annual installment of n periods, calculated by

$$\text{Installment} = \text{Loan request} \times \frac{i}{1-(1+i)^n}, \quad i = \text{interest rate}$$

7. Applicant: Spendable Income (quantitative variable)
8. Guarantor: Spendable Income (quantitative variable)
9. Applicant: Kinds of Income (qualitative variable) applicant's income kind: none (-100), member of the enterprise (0), autonomous (80), employee (100).
10. Guarantor: Kinds of Income (qualitative variable) guarantor's income kind: none (-100), member of the enterprise (0), autonomous (80), employee (100).
11. Applicant: Patrimony (quantitative variable)
12. Guarantor: Patrimony (quantitative variable)
13. Applicant: Bank Exposure (quantitative variable)
14. Guarantor: Bank Exposure (quantitative variable)
15. Applicant: Client (qualitative variable)
16. Applicant: Experience (qualitative variable)

The *neural evaluation* (output) is a number from interval $[0, 1]$: zero means a sharp "no", one means a sharp "yes", while intermediate values express intermediate evaluations.

8.1 The Neural Engine

The output is computed by propagating the inputs throughout the neural network, that is able to processes numerical and *linguistic data.* Our architecture consists of three layers: an input layer with 16 nodes, an intermediate or "hidden" layer with 4 nodes, and one output node.

Each connection is bound to a numerical value, called "weight", which "filters" (through a simple multiplication) the information going through that connection. The nodes of the input layer contain the numeric data presented to the network, and propagate such data through the connections to the intermediate layer.

Each working node combines the information coming from the nodes of the previous layer, and processes data through a two stages mechanism: firstly, each intermediate node aggregates and transforms the data transmitted from the input layer into a single value by multiplying each datum for its connection weight and summing up the results; secondly, the intermediate layer transmits the values obtained to the single output node, which aggregates such values once again and maps the aggregated result into the interval $[0, 1]$ through a particular function (called "sigmoid").

The process of neural learning is based on a table of input-output training examples, and is reflected in changing the connection weights of the network, until the network "learns" to associate each input to its corresponding and desired output, as specified by the table of training examples (the research of the optimal weights is carried out automatically through the backpropagation algorithm).

The construction of the two banks' tables has been carried out within two stages, along each of which 100 cases have been gathered for each credit institution. In the first phase 50 real cases and 50 virtual cases have been gathered for each bank. The real cases have been chosen among those included in their own historical archives, whereas the virtual cases have been generated according to some distributions of probability determined by the people expert in loan concession.

During the second phase, 36 further real cases have been gathered for each credit institution, and 64 virtual cases have been defined, so that the distribution of the four fundamental input variables (spendable income, rate, estate, bank exposure) turned out to be homogenized.

The neural network training, for the two principal ways of evaluation of the banks under study, brought about a complete emulation of their respective tables of examples (about 200 examples). Also within the joined evaluation, obviously associated with criteria less homogeneous, the training process emulated almost all the table (about 99% of the cases). The neural network evaluation software stores each new mortgage loan application for training purposes.

9. A Linguistic Approach to Personnel Evaluation

This case-study presents a method for evaluating human resources in a business context. The proposed approach is based on categories and verbal values represented by linguistic variables [16]. Such a process involves many "raters", which perform a "technical" role, as they provide information to the decision-maker, whose role can be defined as "political". A *rater* expresses his judgements about the possibility that a candidate, X, can get a position, P. We shall suppose that (i) raters and decision-makers are different individuals; (ii) the rater makes use of a rating sheet, where the candidate's profile is compared with the ideal profile; (iii) the rater uses analytical references. The purpose of the procedure is to get homogeneous, clear and reliable judgements.

The evaluation process involves the *Chief Executive Officer* (CEO), the *Direct Evaluator* (DE), usually the direct boss of the candidate, and the *Personnel Manager* (PM).

The DE interviews the candidates and draws up an initial profile; then the PM and the DE check each individual profile and compare all the different profiles, which enables the PM to rank the candidates on a final scale. Such a rating has to be interpreted by the CEO. We have to point out three critical factors:

- The rater gives subjective meanings to the items, because each definition hides ambiguities;
- The rater anchors his judgement to his own experience [see 46];
- The rater aggregates the results [see 80].

The rigidity of the formal procedure of evaluation allows only a small part of the rater's knowledge to be encoded in the organisational memory [1]. The OM is the context within which the rater operates, it is the active structure he continuously evokes during his judgmental process, which provides him with procedures, categories and frames.

The natural language is the best tool to describe organizational situations, since it allows the representation of ambiguities and conflicts usually discarded by formal methods (for sake of simplifications and controllability). If the rater is asked to justify his overall judgement, then he builds up a discourse, whose elements are coherent with the organizational memory or represent private opinions. Such a discourse consists of sentences like,

S_1: "Usually the collaborators of X are satisfied with his decisions";
S_2: "The efficiency of the department headed by X is acceptable";
S_3: "Candidate X has a long-term vision";
S_4: "The scientific reputation of X at is "high" (or "very high")".

These sentences are used by the rater to justify why he judged X "adequate" for the position. We show that a great part of the knowledge embedded in the explanation can be represented by the fuzzy set theory.

"An explanation is a set of words that one person says to another to turn something that is incomprehensible (in some way) into something comprehensible" [98]. Schank (1986) claims that there exists a set of standard explanation questions (EQs) and a standard set of answers to these questions ("Existence theorem").

Therefore a discourse is the set of answers, framed by semiotic [3] and pragmatic [44] perspectives, that the rater gives to the questioner during an explanatory dialogue. The members of a social group will act similarly to such an extent that in the end they may share the same codes used to input meanings to the world [3].

The explication dialogue is seen as an effort to build a possible world, where both the speaker and the respondent can live: this shared world is their public memory. The evaluator pursues many goals during the conversation: he tries to reaffirm his role within the organization and to win the game he is playing with the questioner [44].

How should we manipulate sentences S_1, S_2, ..., S_n in order to be able to judge candidate X? We will assume the following hypotheses,

- The message the rater wishes to send to the CEO can be encoded into several different discourses, ranging from D_0, the discourse without any explication, to D_∞, which is "totally" explicit.
- The rater builds up his discourse D choosing a definite degree of explication, which "balances the needs for exactness and simplicity, and reduces the complexity without oversimplification".

When the rater is asked about the judgement, he supports his synthetic evaluation through a discourse of finite length:

D: "The rating of the candidate X for the position P is V because of S_1, S_2, ..., S_n".

Each sentence S_j evokes one or more situations that are evaluated with respect to one or more categories (or frames) belonging to the organizational memory. For instance, sentence S,

S: "Usually the collaborators of X are highly satisfied with the decisions made by X"

fulfills, to some extent, category C:

C: "Appreciation of the manager by his collaborators".

Sentence S satisfies category C much better than the following one:

S': "Many collaborators of X are not very satisfied with the decisions made by X".

The index $\mu_C(S)$ expresses the degree of satisfaction of sentence S to category C. In this case we have $\mu_C(S') < \mu_C(S)$.

The dialog then starts with an overall judgement like

Rater: "Person characterized by a high professional value, who integrates excellent technical knowledge and professional skills with good managerial skills. He can be entrusted with a wide range of tasks involving high levels of responsibility".

The interviewer "forces" the rater to turn his discourse into other discourses which include several sentences denoting the frames and categories used in evaluating the candidate. Sentences drawn from the evaluator's answers are shown in Table 3.6.

The list of the categories used by the rater, together with the appraisal, is shown in Table 3.7.

The ratings are the result of an implicit process of comparison of the attributes of the real candidate with the characteristics of an "ideal candidate".

Definition 3.2. *There are three definitions of the ideal candidate, namely,*

- *IDEAL CANDIDATE A: "The candidate is ideal when his profile is absolutely excellent";*
- *IDEAL CANDIDATE B: "The candidate is ideal when his profile is coincident with the profile of the position requested by the company";*
- *IDEAL CANDIDATE C: "The candidate is ideal when his profile equals or exceeds the profile of the position requested by the company".*

Symbols $C_{13.1}$, $C_{13.2}$ and $C_{13.3}$ mean that the category

C_{13}: "People able to motivate collaborators"

is supported by three different sentences,

$S_{2.1.1}$: "X is a good boss because his collaborators are highly motivated";

$S_{2.1.1.1}$: "the collaborators of candidate X work hard";

$S_{2.1.1.1.1}$: "the collaborators of candidate X often work overtime".

Therefore,

$$\mu_{C13}(S_{2.1.1}) = HIGH = H,$$
$$\mu_{C13}(S_{2.1.1.1}) = H,$$
$$\mu_{C13}(S_{2.1.1.1.1}) = VH,$$

Table 3.6. Sentences containing interpretations and appraisal of the candidate X.

CODE	SENTENCES
S_1	X has high professional skills
$S_{1,1}$	He is a member of many scientific associations
$S_{1,2}$	He attends at least five international meetings every year
$S_{1,3}$	He achieves satisfactory results from his experience with customers
$S_{1,2,1}$	His papers are appreciated by speakers and audience
$S_{1,3,1}$	Usually customers have a quite good opinion of Mr. X
S_2	X has high managerial skills
$S_{2.1}$	He is able to be a good boss
$S_{2.2}$	He is able to plan
$S_{2.3}$	He is able to manage the resources at his disposal
$S_{2.4}$	He is able to achieve his targets timely
$S_{2.5}$	He is able to cope with complex and unpredicted situations
$S_{2.1.1}$	X is a good boss because his collaborators are highly motivated
$S_{2.1.2}$	His collaborators always speak well of him
$S_{2.2.1}$	He is quite scrupulous when planning the activities he is entrusted with
$S_{2.2.2}$	He devotes much of his time to formal planning
$S_{2.5.1}$	Mr. X is also able to cope with problematic and uncertain situations
$S_{2.1.1.1}$	X's collaborators work hard
$S_{2.2.1.1}$	He often uses methods such as Pert to identify critical program points
$S_{2.1.1.1.1}$	X's collaborators often work overtime

and all these evaluations are attributed to the ideal candidate C.

Table 3.7. Categories used by the rater

Sentence code	Cat. code	Categories	Values
S_1	C_1	People with professional competence	High
$S_{1.1}$	C_2	Scientific Associations	High
$S_{1.2}$	C_3	International Conferences	High
$S_{1.3}$	C_4	Building good relationships with clients	Average
$S_{1.2.1}$	C_5	Technical community appraisal	High
$S_{1.3.1}$	C_6	Customers'appraisal	Above Average
S_2	C_7	People with managerial skills	High
$S_{2.1}$	C_8	Being a boss	High
$S_{2.2}$	C_9	People with planning abilities	High
$S_{2.3}$	C_{10}	People able to manage resources	Average
$S_{2.4}$	C_{11}	People able to achieve results	Average
$S_{2.5}$	C_{12}	Able to manage unpredicted situations	High
$S_{2.1.1}$	C_{13}	People able to motivate collaborators	High
$S_{2.1.2}$	C_{14}	Collaborators'appraisal	High
$S_{2.2.1}$	C_9	People with planning abilities	Average
$S_{2.2.2}$	C_9	People with planning abilities	Average
$S_{2.5.1}$	C_{12}	Able to manage unpredicted situations	Average
$S_{2.1.1.1}$	C_{13}	People able to motivate collaborators	High
$S_{2.2.1.1}$	C_9	People with planning abilities	High
$S_{2.1.1.1.1}$	C_{13}	People able to motivate collaborators	Very High

The principle is to consider scales which contain all the verbal terms used by the rater, and to represent such terms by fuzzy numbers. We will use a four-scale system ranging from a minimum of five to a maximum of eleven levels; the more complex is the structure of the category, the more detailed is the scale. The scales are the following,

- Scale 1: $\{L_1, A_1^-, A_1, A_1^+, H_1\}$,
- Scale 2: $\{VL_2, L_2, A_2^-, A_2, A_2^+, H_2, VH_2\}$,
- Scale 3: $\{VL_3, L_3, A_3^{--}, A_3^-, A_3, A_3^+, A_3^{++}, H_3, VH_3\}$,
- Scale 3: $\{NO, VL_4, L_4, A_4^{--}, A_4^-, A_4, A_4^+, A_4^{++}, H_4, VH_4, EX\}$,

where NO= None, VL= Very Low, L=Low, A^{--} = Lower Lower Average, A^- = Lower Average, A= Average, A^+ = Upper Average, A^{++} = Upper Upper Average, H= High, VH= Very High, and EX = Excellent.

Example 3.3. *Let S be the sentence :*

$$S = \text{"}X \textit{ is a member of several scientific associations"}.$$

The degree of satisfaction of S to category

C_2: *"Scientific Associations"*

is High, that is,

$$\mu_{C_2}(S) = H$$

Each scale contains H, but in this case we choose the simplest scale (Scale 1). As no further explication is requested for the assessment of X in C_2, we put:

$$\mu_{C_2}(X) = \mu_{C_2}(S) = H.$$

The method of evaluation of the candidate X consists of the following three steps:

Step 1: Calculate the score for all the categories which have been elicited through the analysis of the discourse [19];

Step 2: Choose a method to compute the scores according to the concepts of the ideal candidate and the overall score;

Step 3 : Determine a linguistic approximation of the final score.

Step 1: The scores computed for the categories elicited in the example studied before are indicated in Table 3.8.

The score for the generic fuzzy number M has been computed by comparing the fuzzy number with

$$\mu_{MAX}(x) = \begin{cases} x & \text{if } 0 \le x \le 1, \\ 0 & \text{otherwise.} \end{cases}$$

Table 3.8. Scores for the categories.

IDEAL CANDIDATE			
	A	B	C
C_2	0.875		
C_3	0.875		
C_4	0.5		
C_5	0.875		
C_6	0.665		
C_{10}		0.5	
C_{11}		0.5	
C_{14}		0.875	
$C_{9.1}$		0.875	
$C_{9.2}$		0.5	
$C_{9.3}$		0.5	
$C_{9.4}$		0.774	
$C_{13.1}$			0.875
$C_{13.2}$			0.774
$C_{13.3}$			0.91
$C_{12.1}$			0.875
$C_{12.2}$			0.5

and

$$\mu_{MIN}(x) = \begin{cases} 1 - x & \text{if } 0 \leq x \leq 1, \\ 0 & \text{otherwise.} \end{cases}$$

- The right score of M is

$$\mu_R(M) = \sup_x \min\{\mu_M(x), \mu_{MAX}(x)\},$$

- The left score of M is

$$\mu_L(M) = \sup_x \min\{\mu_M(x), \mu_{MIN}(x)\},$$

- The total score of M is

$$\mu_T(M) = \frac{\mu_R(M) + 1 - \mu_L(M)}{2}.$$

Step 2: The scores for the three classes A, B, C, and the overall score of the ideal candidate (IC), are computed using the linguistic quantifier "most", which makes it possible to evaluate the truth of the following statement:

P: "Most of the important qualities of the candidate X are ideal".

The linguistic quantifier "most" might be defined as,

$$\mu_{MOST}(x) = \begin{cases} 1 & \text{if } x \geq 0.9, \\ \frac{5}{3} \times x - 0.5 & \text{if } 0.3 \leq x \leq 0.9, \\ 0 & \text{if } x \leq 0.3, \end{cases}$$

where x is the ratio between the sum of the scores computed at step 1 and the cardinality of the characteristics considered. The results are shown in Table 3.9.

Table 3.9. Results for candidate X.

	A	B	C	IC
Candidate	0.763	0.576	0.81	0.72

Step 3: The quantitative result is transformed into verbal terms by choosing the term with the maximal membership value,

$$\begin{aligned} A_1^+(0.72) &= 0.88, \\ A_2^+(0.72) &= 0.53, \\ A_3^{++}(0.72) &= 0.8, \\ A_4^{++}(0.72) &= 0.8. \end{aligned}$$

So, candidate X is rated "ideal" with (linguistic) degree,

$$A_1^+ = (\text{UPPER AVERAGE})_1.$$

10. An Application to Environmental Policies

Protecting areas of outstanding natural beauty may raise conflict of interest between environmental protection and socio-economic development. One should reconcile the trade-off between new objectives (scientific research as well as recreational activities) and pre-existing production activities (agriculture and forestry), which are not necessarily strictly naturalistic. When dealing with environmental decisions, public authorities frequently use the procedure of analysis and assessment known as *Environmental Impact Assesment* (E.I.A.), which evaluates the impact of new anthropic structures or infrastructures on the environment (for a good survey of the subject, see [77]).

The different points of view obviously lead to the proposal of different solutions to the problem, and therefore the conflicts between them must be solved through the definition of an alternative receiving a high degree of consensus from the social groups involved in the project. A set of individuals (decision-makers, experts, etc.) are called upon to evaluate a finite set of acceptable alternatives following several criteria, and a moderator guides the work session towards a choice which satisfies everybody, or which is considered acceptable by a majority agreed on at the beginning.

The management of such a complex decision making process could be facilitated when the support of computer technologies is used[22, 43].

Indeed group decision support systems (GDSS) are widely advocated and employed to achieve consensus within a dynamic perspective. That is, the experts modify their personal opinions via exchange of information and rational arguments until sufficient agreement (consensus) has been reached.

The interactive system as proposed in [36] applies some methods of the theory of fuzzy sets to group decisions and attempts to process the information contained in natural language, and it allows the groups to establish a ranking of preferences over the alternatives using different algorithms of calculus. The innovatory component, the so-called "consensus module", will be described in the following.

First, for each pair of individuals we derive a degree of agreement as to their preferences between all the pairs of options, next we pool these degrees to obtain a degree of agreement of each pair of individuals as to their preferences between Q_1 (a linguistic quantifier as, e.g., "most", "almost all", "much more than" 50%) pairs of relevant options and, finally, we aggregate these degrees to obtain a degree of agreement of Q_2 (a linguistic quantifier similar to Q_1) pairs of individuals as to their preferences between Q1 pairs or relevant options. This is the degree of consensus sought.

Let the set of alternatives be $A = \{a_1, \dots, a_n\}$, and the set of m individuals be $K = \{1, \dots, m\}$. Suppose each individual $k \in K$ provides his fuzzy preference relation, denoted R_k, whose membership function $\mu_k \colon A \times A \rightarrow [0,1]$, may be defined for each pair of alternatives (a_i, a_j)

by

$$\mu_k(a_i, a_j) = \begin{cases} 1 & \text{if } a_i \text{ is definitely preferred over } a_j, \\ \alpha \in (0.5, 1) & \text{if } a_i \text{ is sligthly preferred over } a_j, \\ 0.5 & \text{if there is no preference (indifference)}, \\ \beta \in (0, 0.5) & \text{if } a_j \text{ is sligthly preferred over } a_i, \\ 0 & \text{if } a_j \text{ is definitely preferred over } a_i. \end{cases}$$

We will use the notation $r_{ij}^k = \mu_k(a_i, a_j)$, where

$$r_{ij}^k + r_{ji}^k = 1,$$

for all i, j, k. The degree of strict agreement between individuals p and q as to their preferences between options a_i and a_j may thus be defined:

$$v_{ij}(p, q) = \begin{cases} 1 & \text{if } r_{ij}^p = r_{ij}^q \\ 0 & \text{otherwise} \end{cases}$$

The relevance of the alternatives is assumed to be a fuzzy subset R of the set of options, A, such that $\mu_R(a_i) \in [0, 1]$ is the degree of relevance of alternative a_i: from 0 standing for "definitely irrelevant" to 1 for "definitely relevant", through all intermediate values. For each pair of options (a_i, a_j) we may now introduce the following index of relevance,

$$b_{ij}^R = \frac{\mu_R(a_i) + \mu_R(a_j)}{2}.$$

The degree of agreement between individuals p and q as to their preferences between all the relevant pairs of alternatives is

$$v_R(p, q) = \frac{\sum_{i=1}^{n-1} \sum_{j=i+1}^{n} v_{ij}(p, q) * b_{ij}^R}{\sum_{i=1}^{n-1} \sum_{j=i+1}^{n} b_{ij}^R},$$

where $*$ denotes a t-norm.

If we introduce a linguistic quantifier Q_1 (e.g., Q_1 = "most"), the degree of agreement between individuals p and q as to their preferences between Q_1 relevant pair of options is

$$v_{Q_1,R}(p, q) = \mu_{Q_1}(v_R(p, q)).$$

In turn, the degree of agreement of all the pairs of individuals as to their preferences between Q_1 relevant pair of options is

$$V_{Q1,R} = \frac{2}{m(m-1)} \sum_{p=1}^{m-1} \sum_{q=p+1}^{m} v_{Q_1,R}(p, q),$$

and, finally, the degree of agreement of Q_2, (Q_2 = "almost all") pairs of individuals as to their preferences between Q_1 relevant pairs of options, called the degree of $Q_1/Q_2/R$-consensus, is

$$\text{con}_R(Q_1, Q_2) = \mu_{Q_2}(V_{Q_1,R})$$

Now we will describe briefly the structure of the software of the DSS (Fig. 3.6). It is essentially based on a machine (moderator, co-ordinator) which contains the data needed by the system as, e.g., the experts' preferences over the alternatives according to different criteria, and the parameters which influence the elaborations.

Each personal computer contains a *Communication Management Module*, which controls the exchange of data and the results of the interactions between the work stations using, e.g., the TPC/IP Protocol. Access to the data and the elaborations (including any possible interruption-abort) are controlled by an *Events Management Module*, which is in charge of and coordinates all the other modules (activating and deactivating them as necessary - in such a way the system set up is "interrupt driven").

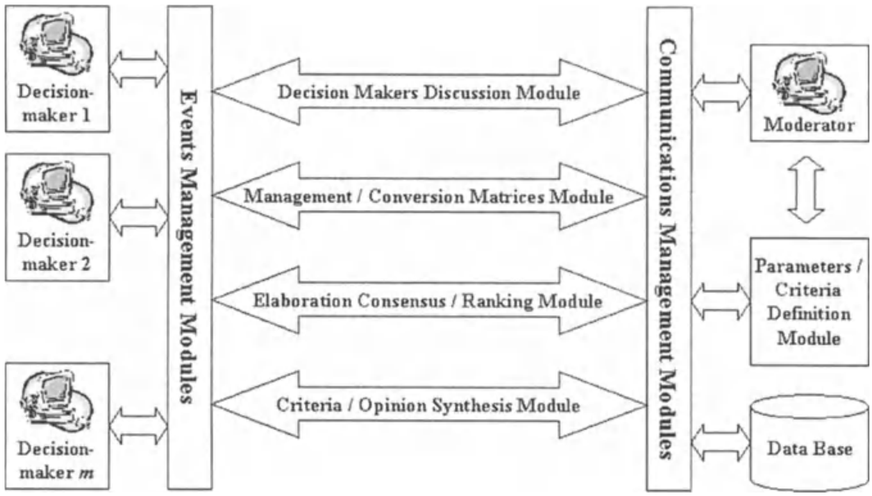


Figure 3.6. Structure of the software of the DSS.

The role of the *Decision-makers Discussion Module* is at least twofold: to help the decision makers to agree on the alternatives and the evaluation criteria to be considered, as well as on the consensus degree required; and to manage the discussion and bargaining both between the moderator and the decision-makers, and directly between the various decision-makers.

The *Management/Conversion Matrices Module* establishes the individuals' preference matrices and elaborates such data activating an appropriate set of algorithms.

The purpose of *Elaboration Consensus/Ranking Module* is to calculate the value of a degree of consensus reached, and to rank both the individual and group preferences.

The *Criteria/Opinion Synthesis Module* provides auxiliary support procedures for non-quantitative assessment of the "distance" between the decision-makers, and a graphic syntesis of the decision-makers' evaluations of the alternatives.

The *Parameters/Criteria Definition Module* determines, at the beginning of each session, the alternatives to assess, the criteria to be considered (and their relevance), the type of the algorithm to be used and the necessary parameters.

10.1 Environment Protection in a Lagoon Ecosystem

Let us now present an example of a consensus reaching session concerning the creation of a natural park in the wetlands of a Lagoon in a region of the North-East of Italy.

Assesment of environmental policies should take into account the conflicts arising from the trade-off between economic activity and environmental protection. To restore particularly neglected areas, and to guide the evolution of natural environment towards a more stable ecological equilibrium need to place precise constraints over land uses.

In our example the area intended for the Regional Lagoon Park is to be subdivided into two zones, each of which will be used for different purposes: one part is meant to be a park, the other one is meant to be a pre-park in a periphery position. The different hypotheses suggested by the public administration have raised strong opposition in various groups within the community, since they perceive the project either as a limitation to important economic activities, or as an obstacle with regard to their needs.

Their positions are not completely homogeneus: some groups definitively oppose the creation of the park for good reasons (for example, hunters), while others, who consider environmental protection as an inevitable issue, are searching for alternatives reducing the socio-economic costs.

Therefore the conflicts concern both the delimitation and the size of the parkland, and the regulations the legislator will have to follow, with reference to national and regional laws.

10.2 Identification of the Interest Groups and Possible Alternatives

We can point out five inetrest groups affected by the creation of a protected area,

1) tourism,
2) agriculture,
3) fish-farmers,
4) ecology movements,
5) hunters.

The first three groups do not prefer the establishment of the park because of the constraints and limitations that could be imposed on their activities.

Ecology movements, that originally proposed the establishment of a regional park for a long time, support the use of the area for leisure purposes. On the other hand, hunters' goal is to sustain free hunting within the boundaries of the park, and they partly identify with other groups such as farmers and fish-farmers because some elements apply to both groups. Now we are able to identify a set of five hypotheses summarizing the different positions of the organizations and the categories involved in the creation of the park. These are,

A_1: Maintain the status quo;

A_2: Create a park only in the public property area and a pre-park in a limited wet area;

A_3: Create a park in the whole wet area and an area of pre-park including a stretch of cultivated land;

A_4: The same as A_3 but permitting more activities both in the park and pre-park areas;

A_5: Create the park in all areas of natural interest in the region with more constraints than in A_4.

Following the E.I.A. methodology, we will evaluate the impact of each alternative on the natural and socio-economic environment. Table 3.10 shows the results of some simulations concerning the economic impacts deriving from activation of the different alternatives. Option 1 is excluded because the process is carried out in a dynamic sense.

Table 3.10. Socio-economic data.

	OPTION 2			OPTION 3-4-5		
	park	pre-park	district	park	pre-park	district
Agriculture						
Employment	15		4.300	50	300	4.300
Added value	0,9		90,3	1,1	6,3	90,3
Stock capital	2		1.880	30	264	1.880
Fish farming						
Employment		30		30		
Added value		1,5		1,5		
Stock capital		3		3		
Lagoon fishing						
Employment		10		10		
Added value		0,2		0,2		
Tourism and *commerce*						
Employment			10.000			10.000
Added value			600			600
No. of tourists			7.7m			7.7m
Local economy						
Employment			33.600			33.600
Added value			1.400			1.400

The existence of alternatives that foresee protected areas of different size makes two different starting points necessary (Table 3.10). Then the impacts relating to the different alternatives are estimated according to percentage variations obtained on the basis of information available from previous experiences and the economic operators' expectations. Simulations show a discrete variability in the results and, the activation of the different projects brings a cost-benefit redistribution among the different zones and the categories.

10.3 Analysis of the Results

The simulation involves an iterative process in which the preference matrices, the ranking of the alternatives and the consensus level are defined at each cycle.

In our context, five groups are asked to evaluate the impact of alternatives on the natural and socio-economic environment on the basis of three different criteria of assessment: social, economic and recreational. From a formal point of view, the results of this phase can be expressed in a matrix format (we obtain five preference matrices for each group).

On the basis of the values of the indices, it is possible to derive the scale of priorities and the relative indices of consistency, which provide a measure of the variance from a perfectly transitive matrix (Saaty proposed to calculate the maximum Eigenvector of the matrix in order to determine the consistency of the initial matrix). The preference matrices are assumed to be reciprocal, and therefore the left lower triangular parts are obviously irrelevant. At first the alternatives are compared using only three values ("strong preferences"):

one - if a_i is definitely preferred over a_j,
half - if there is no preference between the two alternatives,
zero - if a_j is definitely preferred over a_i.

Each group ratifies the superiority of his own proposal over the others, and shows an indifferent attitude towards the remaining pairs of alternatives (Table 3.11).

Table 3.11. Firts cycle preference matrices "strong pereferences".

$$\overset{\textit{Farmers}}{\begin{pmatrix} 1.0 & 1.0 & 1.0 & 1.0 \\ & 0.5 & 0.5 & 0.5 \\ & & 0.5 & 0.5 \\ & & & 0.5 \end{pmatrix}} \quad \overset{\textit{Fishers}}{\begin{pmatrix} 1.0 & 1.0 & 1.0 & 1.0 \\ & 0.5 & 0.5 & 0.5 \\ & & 0.5 & 0.5 \\ & & & 0.5 \end{pmatrix}}$$

$$\overset{\textit{Hunters}}{\begin{pmatrix} 1.0 & 1.0 & 0.5 & 1.0 \\ & 0.5 & 0.0 & 0.5 \\ & & 0.0 & 0.5 \\ & & & 1 \end{pmatrix}} \quad \overset{\textit{Tourism}}{\begin{pmatrix} 1.0 & 1.0 & 0.0 & 1.0 \\ & 0.5 & 0.0 & 0.5 \\ & & 0.0 & 0.5 \\ & & & 0.5 \end{pmatrix}}$$

$$\overset{\textit{Ecology Mov.}}{\begin{pmatrix} 0.5 & 0.5 & 0.5 & 0.0 \\ & 0.5 & 0.5 & 0.0 \\ & & 0.5 & 0.0 \\ & & & 0.0 \end{pmatrix}}$$

It is possible to aggregate the matrices according to the social group or the criterion of assessment, obtaining different rankings. The final synthesis is represented by the ranking - linked to the preference matrix computed by an additional aggregation - is shown in Table 3.13a.

The degree of consistency is high enough, since it is very close to the optimal value. Naturally, the ranking obtained using the "strong preferences" cannot ensure full consensus; in such a case the second part of the iterative system intervenes "quantifying" the "distances" between the different opinions, which will be their consensus degree.

The degree of consensus achievable is likely to be higher than the previous one if we assume a wider spectrum of values, thus permitting the definition of intermediate (fuzzy) degrees of consensus between pairs of alternatives (Table 3.12). In this case the ranking is shown in Table 3.13b.

Table 3.12. Second cycle preference matrices ("reconciled preferences").

Farmers

$$\begin{pmatrix} 0.8 & 0.8 & 0.8 & 0.8 \\ & 0.5 & 0.7 & 0.8 \\ & & 0.1 & 0.5 \\ & & & 0.7 \end{pmatrix}$$

Fishers

$$\begin{pmatrix} 0.8 & 0.8 & 0.8 & 0.8 \\ & 0.5 & 0.7 & 0.8 \\ & & 0.1 & 0.5 \\ & & & 0.7 \end{pmatrix}$$

Hunters

$$\begin{pmatrix} 0.8 & 0.8 & 0.8 & 0.8 \\ & 0.5 & 0.2 & 0.8 \\ & & 0.1 & 0.5 \\ & & & 0.7 \end{pmatrix}$$

Tourism

$$\begin{pmatrix} 0.6 & 0.8 & 0.4 & 0.8 \\ & 0.5 & 0.4 & 0.8 \\ & & 0.1 & 0.6 \\ & & & 0.7 \end{pmatrix}$$

Ecology Mov.

$$\begin{pmatrix} 0.6 & 0.6 & 0.6 & 0.3 \\ & 0.5 & 0.7 & 0.3 \\ & & 0.6 & 0.3 \\ & & & 0.3 \end{pmatrix}$$

We have performed a sensitivity analysis to measure how the degree of consensus changes when the parameters vary.

In our computerized implementation we have considered five intervals for quantifiers Q_1 and Q_2 that cover the whole range of variation. The results pointed out that moving from "close" agreement to a "sufficient" (fuzzier) one, as well as under reconciliating preference relations, leads to higher consensus levels.

Finally, we have observed a tendential growth of consensus when lowering the upper boundary of the interval defining the "most" attribute: this occurs both for the alternatives and for the groups.

Table 3.13a. The ranking from crisp consensus degrees.

Ranking	Eigenvector
1. A_4	0.29237
2. A_1	0.25930
3. A_2	0.20778
4. A_3	0.13062
5. A_5	0.10987

Table 3.13b. The ranking from fuzzy consensus degrees.

Ranking	Eigenvector
1. A_4	0.25326
2. A_2	0.22475
3. A_1	0.20953
4. A_5	0.16140
5. A_3	0.15106

10.4 Summary

In this Section we have presented an approach for consensus reaching, which deals with scarce knowledge of ecological systems and a high level of conflict of interest among the different groups involved.

In this context the theory of fuzzy sets has proved to be an effective and efficient formal tool, which better reflects the real human perception of the very essence and nature of consensus, flexible enough not to require any particular hypothesis about the behaviour or rationality of the experts involved.

References

[1] Argyris C. and Schon D.A., Organizational Learning. A Theory of Action Perspective, Reading (MA), Addison-Wesley, 1978.

[2] Arrow K.J, "Social Choice and Individual Values, Wiley, New-York, 1963.

[3] Barley S.R., "Semiotics and the Study of Occupational and Organizational Cultures", *Administrative Science Quarterly* 28, 1983, 393-413.

[4] Bezdek J., Spillman B. and Spillman R., "A Fuzzy Relation Space for Group Decision Theory", *Fuzzy Sets and Systems* 1, 1978, 255-268.

[5] Bezdek J., Spillman B. and Spillman R., "Fuzzy Measures of Preferences and Consenus in Group Decision Making". In: Fu K.S.(Eds.), Proc. 1977 IEEE Conf. on Decision and Control, 1977, 1303-1309.

[6] Bezdek J., Spillman B. and Spillman R., "Fuzzy Relation Spaces for Group Decision Theory: An Application", *Fuzzy Sets and Systems* 2, 1979, 5-14.

[7] Blin J.M., "Fuzzy Relations in Group Decision Theory", *Journal of Cybernetics* 4, 1974, 17-22.

[8] Blin J.M. and Whinston A.B., "Fuzzy Sets and Social Choice", *Journal of Cybernetics* 3, 1973, 28-33.

[9] Boatto V., Fedrizzi M., Furlani P. and Povellato A., "Fuzzy logic in group decisions: an application to problems of environmental policies", Land and Resources Use Policy, 1991, 62-82.

[10] Bonissone P.P., "A fuzzy sets linguistic approach: theory and applications". In: Gupta M.M. and Sanchez E. (Eds.), Approximate Reasoning in Decision Analysis, North Holland, 1982, 329-339.

[11] Bordogna G., Fedrizzi M., Pasi G., "A Linguistic Modeling of Consensus in Group Decision Making Based on OWA Operators", *IEEE Transactions on Syst., Man, and Cybern.* 27, n.1, 1997, 126-132.

[12] Bortolan G. and Degani R., "A review of some methods for ranking fuzzy subsets", *Fuzzy Sets and Systems* 1, 1985, 1-19.

[13] Bosc P. and Lietard L., "Monotonic Quantified Statements and Fuzzy Integrals", *Proc. NAFIPS/IFIS/NASA Conference*, 1994, 8-12.

[14] Bosc P., Lietard L. and Pivert O., "Quantified Statements and Database Fuzzy Querying". In: P. Bosc and J. Kacprzyk (Eds.), Fuzziness in Database Management Systems, Germany, Physica Verlag, 1995.

[15] Bui T.X., "A Group Decision Support System for Cooperative Multicriteria Group Decision Making", Lecture Notes in Computer Science, Springler-Verlag 290, 1987.

[16] Cannavacciuolo A., Capaldo G., Ventre A., Zollo G., "Linking the fuzzy set theory to organizational routines: a study in personnel evaluation in a large company", Second IEEE International Conf. On Fuzzy Systems, USA, 1993.

[17] Carlsson C., Ehrenberg D., Eklund P., Fedrizzi M., Gustafsson P., Lindholm P., Merkuryeva G., Riissanen T. and Ventre A.G.S., "Consensus in Distributed Soft Environments", European Journal of Operational Research 61, 1992, 165-185.

[18] Carlsson C., Ehrenberg D., Eklund P., Fedrizzi M., et al., "Consensus in distributed soft environments", European Journal of Operational Research 61, 1992, 165-185.

[19] Chen S.J. and Hwang C.L., Fuzzy Multiple Attribute Decision Making - Methods and Applications, Springer-Verlag, 1992.

[20] Dc Groot M.M., "Reaching a Consensus", J. Amer. Stat. Ass. 69, 1974, 118-121.

[21] De Sanctis G. and Gallupe B., "A foundation for the study of group decision support systems", Management Science 33, May 1987, 589-609.

[22] De Sanctis G. and Gallupe B., "Group decision support systems: a new frontier", Data Base, Winter 1985, 3-10.

[23] De Groot M.M., "Reaching a consensus", J. of the American Statistical Association 69, 1974, 118-121.

[24] Delgado M., Verdegay J.L. and Vila M.A., "On Aggregation Operations of Linguistic Labels", International Journal of Intelligent Systems 8, 1993, 351-370.

[25] Dubois D. and Prade H., "Fuzzy numbers: an overview". In: Bezdeck J.C. (Eds.), Analysis of Fuzzy Information, CRC Press, 1987, 3-39.

[26] Dubois D. and Prade H., Fuzzy Sets and Systems, Academic Press, San Diego CA, 1980.

[27] Dubois D. and Prade H., "The use of fuzzy numbers in decision analysis". In: Gupta M.M. and Sanchez E., (Eds.) Fuzzy Information and Decision Processes, North-Holland, 1982, 309-321.

[28] Eom H.B., Lee S.M. and Suh E.H., "Group Decision Support Systems: an essential tool for resolving organizational conflicts", International Journal of Information Management 10, 1990, 215-227.

[29] Fedrizzi M., "A Fuzzy Approach to Modeling of Consensus in Group Decisions", First Workshop on Fuzzy Set Theory in Real Applications, International Issue of Automazione e Strumentazione, November 1993, 9-13.

[30] Fedrizzi M., Fedrizzi M., Marques Pereira R.A., "Consensual Dynamics: an unsupervised learning model in group decision making", in Proc. 3rd Intl. Conference on Fuzzy logic, Neural Nets and Soft Computing IIZUKA '94 (Japan), published by Fuzzy Logic Systems Institute, Japan, 1994, 99-100.

[31] Fedrizzi M., Fedrizzi M., Marques Pereira R.A., "Consensual Dynamics in group decision making", in Proc 6th Intl. Fuzzy Systems Association World Congress IFSA 1995 (San Paulo, Brazil, July 1995), published by International Fuzzy Systems Association IFSA and INPE, San Paulo, Brazil, 1995, 145-148.

[32] Fedrizzi M., Fedrizzi M., Marques Pereira R.A., "Ricostruzione bayesiana di strutture di preferenza debolmente consistenti", Quaderni di Statistica e Matematica Applicata alle Scienze Economico-Sociali, Vol. XVI, n. 3-4, 1994, 21-29.

[33] Fedrizzi M., Fedrizzi M., Marques Pereira R.A., "Soft Consensus and Network Dynamics in Group Decision Making", Int. J. of Int. Syst. 14, 1999, 63-77.

[34] Fedrizzi M., Fuller R., "Stability under fuzzy production rules". In: Proc. of 11th European Meeting on Cybernetics and Systems Research (EMCSR 1992), April 1992, Vienna, Austria.

[35] Fedrizzi M., Kacprzyk J. and Nurmi H., "Consensus Degrees under Fuzzy Preferences Using OWA Operators", Control and Cybernetics 22, 1993, 78-86.

[36] Fedrizzi M., Kacprzyk J. and Zandrozny S., "An Interactive Multi User Decision Support System for Consensus Reaching Processes Using Fuzzy Logic with Linguistic Quantifiers", Decision Support Systems 4, 1988, 313-327.

[37] Fedrizzi M. and Mich L., "Decision using production rules". In: Proc. of Annual Conference of the Operational Research Society of Italy (AIRO 1991). September 18-10. Riva del Garda. Italy, 1991, 118-121.

[38] Fedrizzi, M., "Group Decisions and Consensus: A Model Using Fuzzy Sets Theory (in Italian)", Rivista per le scienze econ. e soc. 9, F. 1, 1986, 12-20.

[39] Fedrizzi, M. and J. Kacprzyk, "On Measuring Consensus in the Setting of Fuzzy Preference Relations". In J. Kacprzyk and M. Roubens (Eds.), Non-Conventional Preference Relations in Decision Making, Springer-Verlag, Berlin - New York - Tokyo, 1988, 129-141.

[40] Filev D.P. and Yager R.R., "A generalized defuzzification method via bad distributions", International Journal of Intelligent Systems 6, 1991, 687-697.

[41] French S., "Consensus of Opinion", Europ. J. Op. Res. 27, 1991, 332-340.

[42] Ginsberg M.L., Essential of artificial intelligence, Morgan Kaufman, San mateo, CA, 1993.

[43] Gray P., "Group decision support systems", Decision Support Systems 3, 1987, 233-242.

[44] Green G.M., Pragmatics and natural Language Understanding, Hillsdale (NY), 1989.

[45] Hellendoorn H., "Design and development of fuzzy systems at Siemens R & D", Second IEEE International Conference on Fuzzy Systems, March 28-April 1, San Francisco, USA, 1993,1365-1370.

[46] Higgins E.T., Strauman T. and Klein R., "Standards and the process of self evaluation: Multiple effects from multiple stages". In: Sorrentino R.M. and Higgins E.T.(Eds.), Handbook of Motivation and Cognition: Foundations of Social Behavior, New York, 1986.

[47] Huber G.P., "Issues in the design of group decision support systems", MIS Quarterly 8, 1984, 195-204.

[48] Huber G.P., "The Design of Group Decision Support Systems", Proc. 16th Hawaii Int. Conf. on Systems Sci. (Honolulu, USA), 1983, 437-444.

[49] Huff A.S. (Ed.), Mapping Strategic Thought, John Wiley, New York, 1990.

[50] Jacob V.S. and Pirkul H., "A framework for supporting distributed group decision-making", Decision Support Systems 8, 1992, 17-28.

[51] Kacprzyk J. and Roubens M., (Eds.) Non conventional Preference Relations in Decision Making, Springer-Verlag, 1988.

[52] Kacprzyk J. and Fedrizzi M., "'Soft' Consensus Measures for Monitoring Real Consensus Reaching Processes under Fuzzy Preferences", Control and Cybernetics 15, 1986, 309-323.

[53] Kacprzyk J. and Fedrizzi M., "A 'Soft' Measure of Consensus in the Setting of Partial (Fuzzy) Preferences", European Journal of Operational Research 34, 1988, 316-325.

[54] Kacprzyk J. and Fedrizzi M., "A human-consistent degree of consensus based on fuzzy logic with linguistic quantifiers", Mathematical Social Sciences 18, 1989, 275-290.

[55] Kacprzyk J., "Group Decision Making with a Fuzzy Linguistic Majority", *Fuzzy Sets and Systems* 18, 1986, 105-118.

[56] Kacprzyk J., Fedrizzi M. and Nurmi H., "Fuzzy Logic with Linguistic Quantifiers in Group Decision Making and Consensus Formation". In: An Introduction to Fuzzy Logic Applications in Intelligent Systems, Yager R.R.and Zadeh L.A. (Eds.), Kluwer, 1992, 263-280.

[57] Kacprzyk J., M. Fedrizzi and H. Nurmi, "Group Decision Making and Consensus under Fuzzy Preferences and Fuzzy Majority", *Fuzzy Sets and Systems* 49, 1992, 21-31.

[58] Kacprzyk J., Multistage Decision Making under Fuzzi-ness, Verlag TUEV Rheinland, Coloene, 1983.

[59] Kacprzyk J., "Collective Decision Making with a Fuzzy Majority Rule", Proc. WOGSC Congress, AFCET, Paris, 1984, 153-159.

[60] Kacprzyk J., "Some 'Commonsense' Solution Concepts in Group Decision Making via Fuzzy Linguistic Quantifiers". In: J. Kacprzyk and R.R. Yager (Eds.), Management Decision Support Systems Using Fuzzy Sets and Possibility Theory, Verlag TUEV Rheinland, Cologne, 1985, 125-135.

[61] Kacprzyk J., "Towards an Algorithmic/Procedural 'Human Consistency' of Decision Support Systems: A Fuzzy Logic Approach". In: W. Karwowski and A. Mital (Eds.), Applications of Fuzzy Sets in Human Factors, Elsevier, Amsterdam, 1986, 101-116.

[62] Kacprzyk J., "On Some Fuzzy Cores and 'Soft' Consensus Measures in Group Decision Making". In: J.C. Bezdek (Ed.), The Analysis of Fuzzy Information, Vol. 2, CRC Press, Boca Raton, 1987, 119-130.

[63] Kacprzyk J., "Towards 'Human Consistent' Decision Support Systems Through Commonsense -Knowledge- Based Decision Making and Control Models: A Fuzzy Logic Approach", Computers and Artificial Intelligence 6, 1987, 97-122.

[64] Kacprzyk J., "Zadeh's Commonsense Knowledge and its Use in Multicriteria, Multistage and Multiperson Decision Making". In: Gupta M.M. et al. (Eds.), Approximate Reasoning in Expert Systems, North-Holland, Amsterdam, 1995, 105-121.

[65] Kacprzyk J., "Group Decision-making with a Fuzzy Majority via Linguistic Quantifiers". Part I: A Consensory–like Pooling; Part II : A Competitive-like Pooling. Cybernetics and Systems: an Int. Journal 16, 1995, 119-129 (Part 1), 131-144 (Part. II).

[66] Kacprzyk J., "Group Decision Making with a Fuzzy Linguistic Majority", *Fuzzy Sets and Systems*, 18, 1996, 105-118.

[67] Kacprzyk J. and Roubens M. (Eds.), Non-Conventional Preference Relations in Decision Making, Springer-Verlag, Berlin - New York - Tokyo, 1988.

[68] Kacprzyk J. and Yager R.R. (Eds.), Management Decision Support Systems Using Fuzzy Sets and Possibility Theory, Verlag TUEV Rheinland, Cologne, 1985.

[69] Kelly F.P., "How a Group reaches Agreement: A Stochastic Model", Math. Soc. Sci. 2, 1981, 1-8.

[70] Kline J.A., "Orientation and Group Consensus", Central States Speech Journal, 1972, 44-55.

[71] Klir G.J. and Yuan B., Fuzzy Sets and fuzzy logic: theory and applications, Prentice Hall, Englewood Cliffs, 1995.

[72] Kowitz A.C. and Knutson T.J., Decision making in Small Groups, Allyn and Bacon, Boston, 1980.

[73] Kraemer K.L. and King J.L., "Computer based systems for cooperative work and group decision making", ACM Computing Surveys 20, 1988, 115-146.

[74] Kuzmin V.B., Construction of Group Decisions in the Spaces of Non-Fuzzy and Fuzzy Binary Relations (in Russian), Nauka, Moscow, 1982.

[75] Kuzmin V.B. and Ovchinnikov S.V., "Group Decisions I: In Arbitrary Spaces of Fuzzy Binary Relations", *Fuzzy Sets and Systems*, 4, 1980, 53-62.

[76] Kuzmin V.B. and Ovchinnikov, "Design of Group Decisions II: In Arbitrary Spaces of Fuzzy Binary Relations", *Fuzzy Sets and Systems*, 4, 1980, 153-165.

[77] Lee N., Environmental impact assessment: a review, Applied Geography 3, 1983.

[78] Lefons E., Pazienza M.T., Silvestri A., Tangorra F., Corfiati L., De Giacomo P., "An algebraic model for systems of psychically interacting subjects". In: Dubisson B., (Ed.) Information and Systems, Oxford, 1977, 155-163.

[79] Lehrer K. and Wagner C., Rational Consensus in Science and Society, Reldel. Dordrecht- Boston, 1991.

[80] Lowe T.E., "Eight ways to ruine a performance review", Personnel Journal, 1986.

[81] Lower B., Guest Ed., Special Issue on Consensus, Synthese 62, n. 1., 1985.

[82] Marques Pereira R.A. and Simone P., Working Paper, DISA, University of Trento, 1999.

[83] Marques Pereira R.A. and Geiger G., "Beyond step edges: 2nd order surface reconstruction", Quaderni di Statistica e Matematica Applicata alle Scienze Economico-Sociali, Vol. XV, n. 2, 1993, 45-55.

[84] Marques Pereira R.A. and Geiger G., "Surface reconstruction from essential data", Quaderni di Statistica e Matematica Applicata alle Scienze Economico-Sociali, Vol. XV, n. 1, 1993, 37-49.

[85] Martelli A., Scenari e strategie, ETAS Libri, Milano (Italy), 1988.

[86] Martelli A., Analisi strategica mediante scenari, ETAS Libri, Milano (Italy), 1992.

[87] Mich L., Fedrizzi M., Gaio L., "Approximate reasoning in the modeling of consensus in group decisions". In: Klement E.P., Slany W. (Eds.), Fuzzy Logic in Artificial Intelligence, Lectures Notes in Artificial Intelligence, Vol. 695, Springler-Verlag, Berlin, 1993, 91-102.

[88] Moretti A., Decisione manageriale e mappe cognitive: strumenti e applicazioni, Univ. of Venezia-DEDA, Working Paper n.4/93, 1993.

[89] Nunamaker J.F., Dennis A.R., Valacich J.S., Vogel D.R., George J.F., "Electronic meeting systems to support group work", Communications of the ACM, Vol. 34, n. 7, July 1991, 40-61.

[90] Nurmi H., "Approaches to Collective Decision making with Fuzzy Preference Relation", *Fuzzy Sets and Systems* 6, 1981, 187-198.

[91] Ovchinnikov S., "Social choice and Lukasiewicz logic, *Fuzzy Sets and Systems,* 43(1991) 275-289.

[92] Prade H., "A two-layer Fuzzy Pattern Matching Procedure for the Evaluation of Conditions Involving Vague Quantifiers", Journal of Intelligent and Robotic Systems 3, 1990, 93-101.

[93] Ragade R.K., "Fuzzy Sets in Communication Systems and in Consensus Formation Systems", J. Cybern. 6, 1976, 21-38.

[94] Ragade R.K., "Profile Transformation Algebra and Group Consensus Formation Through Fuzzy Sets". In: M.M. Gupta, G.N. Saridis and B.R. Gaines (Eds.), Fuzzy Automata and Decision Processes, North-Holland, Amsterdam, 1977, 331-356.

[95] Runkler T.A. and Glesner M., "A set of axioms for defuzzification strategies-towards a theory of rational defuzzification operators", 2nd IEEE International

Conference on Fuzzy Systems, March 28-April 1, San Francisco, USA, 1993, 1161-1166.

[96] Saade J.J. and Schwarzlauder H., "Ordering fuzzy sets over the real line: an approach based on decision making under uncertainty", *Fuzzy Sets and Systems* 50, 1992, 237-246.

[97] Schank R., "Language and Memory". In: Norman D.A. (Ed.), Perspectives on Cognitive Sciences, Norwood (NY), 1981.

[98] Schank R., Explanation Patterns: Understanding Mechanically and Creatively, Hillsdale (NY), 1986.

[99] Shakun M., "Airline buyout: evolutionary system design and problem restructuring in group decision and negotiation", Management Science 37, 1991, 1291-1303.

[100] Skala H., "Arrow's impossibility theorem: some new aspects". In: Gottinger H., Leinfellner W. (Eds.), Decision theory and social ethics, Reidel D., 1978, 215-225.

[101] Spillman B., Bezdek J. and Spillman R., "Coalition Analysis with Fuzzy Sets", Kybernetes 8, 1979, 203-211.

[102] Spillman B., Spillman R. and Bezdek J., "A Fuzzy Analysis of Consensus in Small Groups". In: P.P. Wang and S.K. Chang (Eds.), Fuzzy sets Theory and Applications to Policy, Analysis and Information Systems, Plenum, New York, 1980, 291-308.

[103] Spillman B., Spillman R. and Bezdek J., "Development of an Instrument for the Dynamic Measurement of Consensus", Comm. Memo., 1979, 1-12.

[104] Sprague, "A framework for the development of decision support systems", MIS Quarterly 4, 1-26.

[105] Takahara Y., Iijima J., Shiba N., "A hyerarchy of decision making concepts: conceptual foundation of decision support systems", International Journal of General Systems 20, 1992, 359-378.

[106] Tanino T., "Fuzzy Preference Ordenings in Group Decision Making", *Fuzzy Sets and Systems*, 12, 1984, 117-131.

[107] Tanino T., "Fuzzy Preference Relations in Group Decision Making". In: J. Kacprzyk and M. Roubens (Eds.). Non-Conventional Preference Relations in Decision Making, Springer-Verlag, Berlin, 1988, 54-71.

[108] Toulmin S., The uses of argument, CUP, Cambridge, 1958.

[109] Tong R.M. and Bonissone P.P., "A linguistic approach to decision making with fuzzy sets", IEEE Transactions on Systems Man and Cybernetics 10, 1980, 716-723.

[110] Yager R.R., "Interpreting Linguistically Quantified Propositions", International Journal of Intelligent Systems 9, 1994, 541-569.

[111] Yager R.R., "Non Numeric Multi Criteria Multi-Person Decision Making", Group Decision and Negotiation 2, 1993, 81-93.

[112] Yager R.R., "A General Approach to Criteria Aggregation Using Fuzzy Measures", International Journal of Man-Machine Studies 38, 1993, 187-213.

[113] Yager R.R., "Applications and Extensions of OWA Aggregations", International Journal of Man-Machine Studies 37, 1992, 103-132.

[114] Yager R.R., "On Ordered Weighted Averaging Aggregation Operators in Multicriteria Decision Making", IEEE Trans. on Systems Man and Cybernetics 18, 1988, 183-190.

[115] Yager R.R., "Quantifier Guided Aggregation Using OWA Operators", Technical Report MII-1504, Iona College, Machine Intelligence Institute, New Rochelle, NY 10801, November 1994.

[116] Yager R.R., "A weighted median aggregation", International Journal of Uncertainty, Fuzziness and Knowledge-Based Systems 2, n.1, 1994, 101-103.

[117] Yager R.R., "Quantifiers in the Formulation of Multiple Objective Decision Functions", *Information Sciences* 31, 1993, 107-139.

[118] Zadeh L.A., "Outline of a new approach to the analysis of complex systems and decision processes", *IEEE Transactions on Systems Man and Cybernetics* 3, 1973, 28-44.

[119] Zadeh L.A., "The concept of a linguistic variable and its application to approximate reasoning", *Information Sciences* (Part I) 8, 1975, 199-249; (Part II) 8, 301-357; (Part III) 9, 1976, 43-80.

[120] Zadeh L.A., "A Computational Approach to Fuzzy Quantifiers in Natural Languages", *Computer Mathematics with applications* 9, 1983, 149-183.

[121] Zadeh L.A., "A Theory of Commonsense Knowledge". In: H.J. Skala, S. Termini and E. Trillas (Eds.), Aspects of Vagueness, Reldel, Dordrecht, 1984, 257-295.

[122] Zadeh L.A., "Syllogistic Reasoning in Fuzzy Logic and its Application to Usuality and Reasoning with Dispositions", *IEEE Trans. on Syst., Man and Cybern.*, SMC-15, 1985, 754-763.

Chapter 4

FUZZY REAL OPTIONS FOR STRATEGIC PLANNING

To have a *real option* means to have the possibility for a certain period to either choose for or against making an invetsment decision, without binding oneself up front. The real option rule is that one should invest today only if the net present value is high enough to compensate for giving up the value of the option to wait. Because the option to invest loses its value when the investment is irreversibly made, this loss is an opportunity cost of investing. The main question that a management group must answer for a deferrable investment opportunity is: *How long do we postpone the investment, if we can postpone it, up to T time periods?* In this paper we shall introduce a (heuristic) real option rule in a fuzzy setting, where the present values of expected cash flows and expected costs are estimated by trapezoidal fuzzy numbers. Following Carlsson and Fullér [10] shall determine the optimal exercise time by the help of possibilistic mean value and variance of fuzzy numbers.

Options are known from the financial world where they represent the right to buy or sell a financial value, mostly a stock, for a predetermined price (the exercise price), without having the obligation to do so. The actual selling or buying of the underlying value for the predetermined price is called exercising your option. One would only exercise the option if the underlying value is higher than the exercise price in case of a call option (the right to buy) or lower than the exercise prise in the case of a put option (the right to sell).

In 1973 Black and Scholes [4] made a major breakthrough by deriving a differential equation that must be satisfied by the price of any derivative security dependent on a non-dividend paying stock. For risk-neutral

C. Carlsson et al., *Fuzzy Logic in Management*

investors the *Black-Scholes pricing formula* for a call option is

$$C_0 = S_0 N(d_1) - X e^{-rT} N(d_2),$$

where

$$d_1 = \frac{\ln(S_0/X) + (r + \sigma^2/2)T}{\sigma\sqrt{T}}, \quad d_2 = d_1 - \sigma\sqrt{T},$$

and where, C_0 is the option price, S_0 is the current stock price, $N(d)$ is the probability that a random draw from a standard normal distribution will be less than d, X is the exercise price, r is the annualized continuously compounded rate on a safe asset with the same maturity as the expiration of the option, T is the time to maturity of the option (in years) and σ denotes the standard deviation of the annualized continuously compounded rate of return of the stock.

In 1973 Merton [13] extended the Black-Scholes option pricing formula to dividends-paying stocks as

$$C_0 = S_0 e^{-\delta T} N(d_1) - X e^{-rT} N(d_2), \tag{4.1}$$

where,

$$d_1 = \frac{\ln(S_0/X) + (r - \delta + \sigma^2/2)T}{\sigma\sqrt{T}}, \quad d_2 = d_1 - \sigma\sqrt{T},$$

where δ denotes the dividends payed out during the life-time of the option.

Real options in option thinking are based on the same principles as financial options. In real options, the options involve "real" assets as opposed to financial ones [1]. To have a "real option" means to have the possibility for a certain period to either choose for or against making an invetsment decision, without binding oneself up front. For example, owning a power plant gives a utility the opportunity, but not the obligation, to produce electricity at some later date.

Real options can be valued using the analogue option theories that have been developed for financial options, which is quite different from traditional discounted cashflow investment approaches. In traditional investment approaches investments activities or projects are often seen as *now or never* and the main question is whether to go ahead with an investment *yes or no* [3].

Formulated in this way it is very hard to make a decision when there is uncertainty about the exact outcome of the investment. To help with these tough decisions valuation methods as *Net Present Value* (NPV) or *Discounted Cash Flow* (DCF) have been developed. And since these methods ignore the value of flexibility and discount heavily for external uncertainty involved, many interesting and innovative activities and projects are cancelled because of the uncertainties.

However, only a few investment projects are now or never. Often it is possible to delay, modify or split up the project in strategic components which generate important learning effects (and therefore reduce uncertainty). And in those cases option thinking can help [12]. The new rule, derived from option pricing theory (4.1), is that you should invest today only if the net present value is high enough to compensate for giving up the value of the option to wait. Because the option to invest loses its value when the investment is irreversibly made, this loss is an opportunity cost of investing. Following Leslie and Michaels [11] we will compute the value of a real option by

$$\mathrm{ROV} = S_0 e^{-\delta T} N(d_1) - X e^{-rT} N(d_2), \tag{4.2}$$

where,

$$d_1 = \frac{\ln(S_0/X) + (r - \delta + \sigma^2/2)T}{\sigma\sqrt{T}}, \quad d_2 = d_1 - \sigma\sqrt{T},$$

and where ROV denotes the current real option value, S_0 is the present value of expected cash flows, X is the (nominal) value of fixed costs, σ quantifies the uncertainty of expected cash flows, and δ denotes the value lost over the duration of the option.

We illustrate the main difference between the traditional (passive) NPV decision rule and the (active) real option approach by an example quoted from ([11], page 10):

"...another oil company has the opportunity to acquire a five-year licence on block. When developed, the block is expected to yield 50 million barrels of oil. The current price of a barell of oil from this field is \$10 and the present value of the development costs is \$600 million. Thus the NPV of the project opportunity is

50 million × \$10 - \$600 million = -\$100 million.

Faced with this valuation, the company would obviously pass up the opportunity. But what would option valuation make of the same case? To begin with, such a valuation would recognize the importance of uncertainty, which the NPV analysis effectively assumes away. There are two major sources of uncertainty affecting the value of the block: the quantity and the price of the oil. One can make a reasonable estimate of the quantity of the oil by analyzing historical exploration data in geologically similar areas. Similarly, historical data on the variablity of oil prices is readily available.

Assume for the sake of argument that these two sources of uncertainty jointly result in a 30 percent standard deviation (σ) around the growth rate of the value of operating cash inflows. Holding the option also obliges one to incur the annual fixed costs of keeping the reserve active - let us say, \$15 million. This represents a dividend-like payout of three percent (i.e. 15/500) of the value of the assets.

We already know that the duration of the option, T, is five years and the risk-free rate, r, is 5 percent, leading us to estimate option value at

$$\begin{aligned}\text{ROV} &= 500 \times e^{-0.03\times 5} \times 0.58 - 600 \times e^{-0.05\times 5} \times 0.32 \\ &= \$251 \ \text{ million - } \$151 \ \text{ million} = \$100 \ \text{ million.''}\end{aligned}$$

The main question that a company must answer for a deferrable investment opportunity is: *How long do we postpone the investment up to T time periods?* To answer this question, Benaroch and Kauffman ([2], page 204) suggested the following decision rule for optimal investment strategy: Where the maximum deferral time is T, make the investment (exercise the option) at time t^*, $0 \leq t^* \leq T$, for which the option, C_{t^*}, is positive and attends its maximum value,

$$C_{t^*} = \max_{t=0,1,\ldots,T} C_t = V_t e^{-\delta t} N(d_1) - X e^{-rt} N(d_2), \tag{4.3}$$

where

$$\begin{aligned}V_t &= \text{PV}(\text{cf}_0, \ldots, \text{cf}_T, \beta_P) - \text{PV}(\text{cf}_0, \ldots, \text{cf}_t, \beta_P) \\ &= \text{PV}(\text{cf}_{t+1}, \ldots, \text{cf}_T, \beta_P),\end{aligned}$$

that is,

$$V_t = \text{cf}_0 + \sum_{j=1}^{T} \frac{\text{cf}_j}{(1+\beta_P)^j} - \text{cf}_0 - \sum_{j=1}^{t} \frac{\text{cf}_j}{(1+\beta_P)^j} = \sum_{j=t+1}^{T} \frac{\text{cf}_j}{(1+\beta_P)^j},$$

and cf_t denotes the expected cash flow at time t, and β_P is the risk-adjusted discount rate (or required rate of return on the project).

Of course, this decision rule has to be reapplied every time new information arrives during the deferral period to see how the optimal investment strategy might change in light of the new information.

It should be noted that the fact that real options are like financial options does not mean that they are the same. Real options are concerned about strategic decisions of a company, where degrees of freedom are limited to the capabilities of the company. In these strategic decisions different stakeholders play a role, especially if the resources needed for an investment are significant and thereby the continuity of the company is at stake. Real options therefore, always need to be seen in the larger context of the company, whereas financial options can be used freely and independently.

1. A Fuzzy Approach to Real Option Valuation

Usually, the present value of expected cash flows can not be be characterized by a single number. However, our experiences with the Waeno research project on giga-investments[1] show that managers are able to estimate the present value of expected cash flows by using a trapezoidal possibility distribution of the form

$$\tilde{S}_0 = (s_1, s_2, \alpha, \beta),$$

i.e. the most possible values of the present value of expected cash flows lie in the interval $[s_1, s_2]$ (which is the core of the trapezoidal fuzzy number $\tilde{S}_0$), and $(s_2 + \beta)$ is the upward potential and $(s_1 - \alpha)$ is the downward potential for the present value of expected cash flows.

In a similar manner one can estimate the expected costs by using a trapezoidal possibility distribution of the form

$$\tilde{X} = (x_1, x_2, \alpha', \beta'),$$

i.e. the most possible values of expected cost lie in the interval $[x_1, x_2]$ (which is the core of the trapezoidal fuzzy number $\tilde{X}$), and $(x_2 + \beta')$ is the upward potential and $(x_1 - \alpha')$ is the downward potential for expected costs.

Following Carlsson and Fullér [10] we suggest the use of the following (heuristic) formula for computing fuzzy real option values

$$\text{FROV} = \tilde{S}_0 e^{-\delta T} N(d_1) - \tilde{X} e^{-rT} N(d_2), \tag{4.4}$$

where,

$$d_1 = \frac{\ln(E(\tilde{S}_0)/E(\tilde{X})) + (r - \delta + \sigma^2/2)T}{\sigma\sqrt{T}}, \quad d_2 = d_1 - \sigma\sqrt{T}, \tag{4.5}$$

and where, $E(\tilde{S}_0)$ denotes the possibilistic mean value [6] of the present value of expected cash flows, $E(\tilde{X})$ stands for the the possibilistic mean value of expected costs and $\sigma := \sigma(\tilde{S}_0)$ is the possibilistic variance [6] of the present value expected cash flows. Using formulas (2.3 - 2.4) for arithmetic operations on trapezoidal fuzzy numbers we find

$$\begin{aligned} \text{FROV} &= (s_1, s_2, \alpha, \beta)e^{-\delta T} N(d_1) - (x_1, x_2, \alpha', \beta')e^{-rT} N(d_2) = \\ &(s_1 e^{-\delta T} N(d_1) - x_2 e^{-rT} N(d_2), s_2 e^{-\delta T} N(d_1) - x_1 e^{-rT} N(d_2), \\ &\alpha e^{-\delta T} N(d_1) + \beta' e^{-rT} N(d_2), \beta e^{-\delta T} N(d_1) + \alpha' e^{-rT} N(d_2)). \end{aligned} \tag{4.6}$$

[1] A Project on Giga-investments, financied by Tekes under contract No. 40470/00.

We have a specific context for the use of the real option valuation method with fuzzy numbers, which is the main motivation for our approach. Giga-investments require a basic investment exceeding 300 million euros and they normally have a life length of 15-25 years. The standard approach with the NPV or DCF methods is to assume that uncertain revenues and costs associated with the investment can be estimated as probabilistic values, which in turn are based on historic time series and observations of past revenues and costs.

It should be clear that the relevance of historic data diminishes very quickly after 2-3 years and that it is not worthwhile to claim that the time series have any predictive value after 5 years (and even much more so for 15-25 years ahead). In the classical real options valuation methods this problem has been met by assuming that either (i) the stock market is able to find a price for the impact of the investment on the stock market value of the shares of the investing company (somehow doubtful for 15-25 years ahead), or that (ii) the uncertain revenues and costs are purely stochastic phenomena (described by, for instance, geometric Brownian motion).

We have discovered that giga-investments actually influence the end-user markets in *non-stochastic ways* and that they are normally significant enough to have an impact on market strategies, on technology strategies, on competitive positions and on business models. Thus, the use of assumptions on purely stochastic phenomena is not well-founded.

Example 4.1. *Suppose we want to find a fuzzy real option value under the following assumptions,*

$$\tilde{S}_0 = (\$400 \text{ million}, \$600 \text{ million}, \$150 \text{ million}, \$150 \text{ million}),$$

$r = 5\%$ *per year,* $T = 5$ *years,* $\delta = 0.03$ *per year and*

$$\tilde{X} = (\$550 \text{ million}, \$650 \text{ million}, \$50 \text{ million}, \$50 \text{ million}),$$

First calculate

$$\sigma(\tilde{S}_0) = \sqrt{\frac{(s_2 - s_1)^2}{4} + \frac{(s_2 - s_1)(\alpha + \beta)}{6} + \frac{(\alpha + \beta)^2}{24}} = \$154.11 \text{ million},$$

i.e. $\sigma(\tilde{S}_0) = 30.8\%$,

$$E(\tilde{S}_0) = \frac{s_1 + s_2}{2} + \frac{\beta - \alpha}{6} = \$500 \text{ million},$$

and

$$E(\tilde{X}) = \frac{x_1 + x_2}{2} + \frac{\beta' - \alpha'}{6} = \$600 \text{ million},$$

furthermore,

$$N(d_1) = N\left(\frac{\ln(600/500) + (0.05 - 0.03 + 0.308^2/2) \times 5}{0.308 \times \sqrt{5}}\right) = 0.589,$$

$$N(d_2) = 0.321.$$

Thus, from (4.4) we obtain the fuzzy value of the real option as

$$\text{FROV} = (\$40.15 \text{ million}, \$166.58 \text{ million}, \$88.56 \text{ million}, \$88.56 \text{ million}).$$

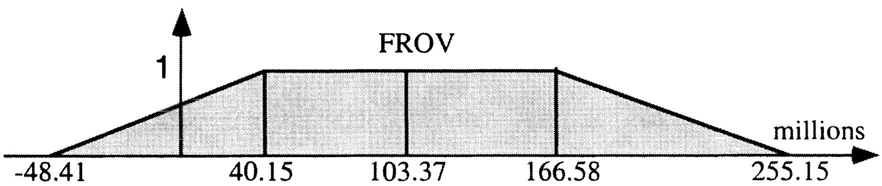


Figure 4.1. The possibility distribution of real option values.

The expected value of FROV is \$103.37 million and its most possible values are bracketed by the interval

$$[\$40.15 \text{ million}, \$166.58 \text{ million}],$$

the downward potential (i.e. the maximal possible loss) is \$48.41 million, *and the upward potential (i.e. the maximal possible gain) is \$255.15* million. *From Fig. 4.1 we can see that the set of most possible values of fuzzy real option* [40.15, 166.58] *is quite big. It follows from the huge uncertainties associated with cash inflows and outflows.*

Following Carlsson and Fullér [5, 7, 8, 9] we shall generalize the probabilistic decision rule for optimal investment strategy to a fuzzy setting: Where the maximum deferral time is T, make the investment (exercise the option) at time t^*, $0 \leq t^* \leq T$, for which the option, $\tilde{C}_{t^*}$, attends its maximum value,

$$\tilde{C}_{t^*} = \max_{t=0,1,\ldots,T} \tilde{C}_t = \tilde{V}_t e^{-\delta t} N(d_1) - \tilde{X} e^{-rt} N(d_2), \qquad (4.7)$$

where

$$\begin{aligned}\tilde{V}_t &= \text{PV}(\tilde{\text{cf}}_0, \ldots, \tilde{\text{cf}}_T, \beta_P) - \text{PV}(\tilde{\text{cf}}_0, \ldots, \tilde{\text{cf}}_t, \beta_P) \\ &= \text{PV}(\tilde{\text{cf}}_{t+1}, \ldots, \tilde{\text{cf}}_T, \beta_P),\end{aligned}$$

that is,

$$\tilde{V}_t = \tilde{\text{cf}}_0 + \sum_{j=1}^{T} \frac{\tilde{\text{cf}}_j}{(1+\beta_P)^j} - \tilde{\text{cf}}_0 - \sum_{j=1}^{t} \frac{\tilde{\text{cf}}_j}{(1+\beta_P)^j}$$
$$= \sum_{j=t+1}^{T} \frac{\tilde{\text{cf}}_j}{(1+\beta_P)^j},$$

where $\tilde{\text{cf}}_t$ denotes the expected (fuzzy) cash flow at time t, β_P is the risk-adjusted discount rate (or required rate of return on the project). However, to find a maximizing element from the set

$$\{\tilde{C}_0, \tilde{C}_1, \ldots, \tilde{C}_T\},$$

is not an easy task because it involves ranking of trapezoidal fuzzy numbers.

In our computerized implementation we have employed the following value function to order fuzzy real option values, $\tilde{C}_t = (c_t^L, c_t^R, \alpha_t, \beta_t)$, of trapezoidal form:

$$v(\tilde{C}_t) = \frac{c_t^L + c_t^R}{2} + r_A \cdot \frac{\beta_t - \alpha_t}{6},$$

where $r_A \geq 0$ denotes the degree of the investor's risk aversion. If $r_A = 0$ then the (risk neutral) investor compares trapezoidal fuzzy numbers by comparing their possibilistic expected values, i.e. he does not care about their downward and upward potentials.

1.1 Real Options in Strategic Planning

There has been a suspicion for some time that capital invested in very large projects, with an expected life cycle of more than a decade is not very productive and that the overall activity around them is not very profitable. There is even some fear (which actually was articulated in the Waeno research program in Finland) that giga-investments in production facilities may consume capital, which could be used more effectively and more profitably in investment opportunities offered by the global financial markets. If the opportunities offered by a global market are used as reference points, arguments may be construed to show that long-term investments in production facilities will destroy capital. If this conclusion was to be made by risk-taking investors, the consequences may be disastrous for major parts of the traditional industry, which - by the way - forms the backbone of the economy and the welfare of most industrial nations.

This discussion was real and urgent during the boom of the so-called Internet economy in 1998-2000, during which the market values of dotcom-start ups exceeded the market values of multinational corporations running tens of pulp and paper mills in a dozen countries.

Giga-investments made in the paper- and pulp industry, in the heavy metal industry and in other base industries, today face scenarios of slow (or even negative) growth (2-3 % p.a.) in their key markets and a growing over-capacity in Europe. The energy sector faces growing competition with lower prices and cyclic variations of demand. There is also some statistics, which shows that productivity improvements in these industries have slowed down to 1-2 % p.a., which opens the way for effective com-petitors to gain footholds in their main markets.

Giga-investments compete for major portions of the risk-taking capital, and as their life is long, compromises are made on their short-term productivity. The short-term productivity may not be high, as the life-long return of the investment may be calculated as very good. Another way of motivating a giga-investment is to point to strategic advantages, which would not be possible without the investment and thus will offer some indirect returns.

There are other issues. Global financial markets make sure that capital cannot be used non-productively, as its owners are offered other opportunities and the capital will move (often quite fast) to capture these opportunities. The capital market has learned 'the American way', i.e. there is a shareholder dominance among the actors, which has brought (often quite short-term) shareholder return to the forefront as a key indicator of success, profitability and productivity.

There are lessons learned from the Japanese industry, which point to the importance of immaterial investments. These lessons show that investments in buildings, production technology and supporting technology will be enhanced with immaterial investments, and that these are even more important for reinvestments and for gradually growing maintenance investments.

The core products and services produced by giga-investments are enhanced with life-time service, with gradually more advanced maintenance and financial add-on services. These make it difficult to actually assess the productivity and profitability of the original giga-investment, especially if the products and services are repositioned to serve other or emerging markets.

New technology and enhanced technological innovations will change the life cycle of a giga-investment. The challenge is to find the right time and the right innovation to modify the life cycle in an optimal way. Technology providers are involved through-out the life cycle of a giga-investment, which should change the way in which we assess the profitability and the productivity of an investment.

Decision trees are excellent tools for making financial decisions where a lot of vague information needs to be taken into account. They provide an effective structure in which alternative decisions and the implications of taking those decisions can be laid down and evaluated. They also help us to form an accurate, balanced picture of the risks and rewards that can result from a particular choice.

In our empirical cases we have represented strategic planning problems by dynamic decision trees, in which the nodes are projects that can be deferred or postponed for a certain period of time. Using the theory of real options we have been able to identify the optimal path of the tree, i.e. the path with the biggest real option value in the end of the planning period.

2. Nordic Telekom Inc.

The World's telecommunications markets are undergoing a revolution. In the next few years mobile phones may become the World's most common means of communication, opening up new opportunities for systems and services. Characterized by large capital investment requirements under conditions of high regulatory, market, and technical uncertainty, the telecommunications industry faces many situations where strategic initiatives would benefit from real options analysis.

As the FROV method is applied to the telecom markets context and to the strategic decisions of a telecom corporation we will have to understand in more detail how the real option values are formed. In Fig. 4 the impact of a number of factors is summarized on the formation of the real option values.

The FROV will increase with an increasing volatility of cash flow estimates. The corporate management can be proactive and find (i) ways to expand to new markets, (ii) product innovations and (iii) (innovative) product combinations as end results of their strategic decisions. If the current value of expected cash flows will increase, then the FROV will increase. A proactive management can influence this by (for instance) developing market strategies or developing subcontractor relations.

The FROV will decrease if value is lost during the postponement of the investment, but this can be countered by either creating business barriers for competitors or by better managing key resources. An increase in riskless returns will increase the FROV, and this can be further enhanced by closely monitoring changes in the interest rates.

If the expected value of fixed costs goes up, the FROV will decrease as opportunities of operating with less cost are lost. This can be countered by using the postponement period to explore and implement production scalability benefits and/or to utilise learning benefits.

The longer the time to maturity, the greater will be the FROV. A proactive manage-ment can make sure of this development by (i) maintaining protective barriers, (ii) communicating implementation possibilities and (iii) maintaining a technological lead.

The following example outlines the methodology used (to keep confidentiality we have modified the real setup) in the the Nordic Telekom Inc. (NTI) case:

Example 4.2. *Nordic Telekom Inc. is one of the most successful mobile communications operators in Europe*[2] *and has gained a reputation among its competitors as a leader in quality, innovations in wireless technology and in building long-term customer relationships.*

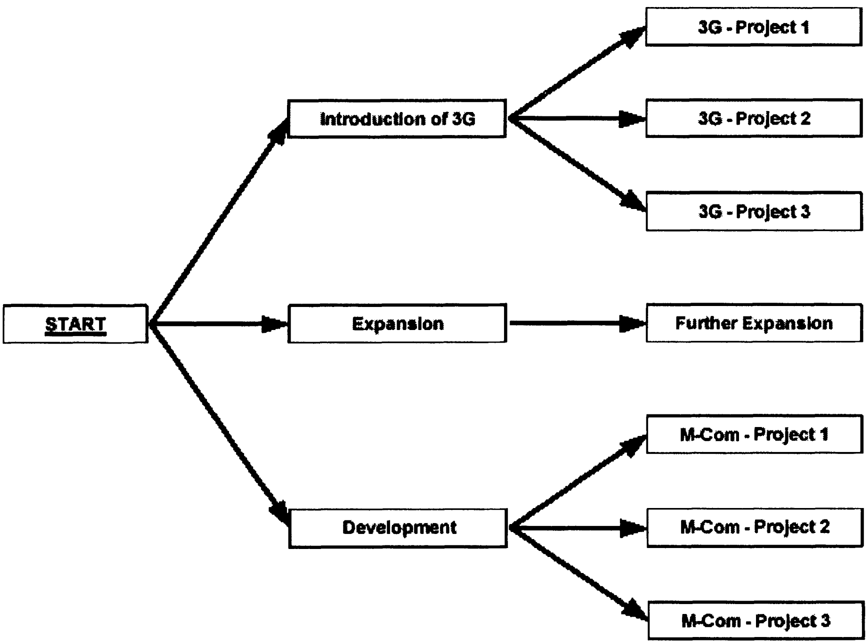


Figure 4.2. A simplified decision tree for Nordic telecom Inc.

[2]NTI is a fictional corporation, but the dynamic tree model of strategic decisions has been succesfully implemented for the 4 Finnish companies which participate in the Waeno project on giga-investments.

Still it does not have a dominating position in any of its customer segments, which is not even advisable in the European Common market, as there are always 4-8 competitors with sizeable market shares. NTI would, nevertheless, like to have a position which would be dominant against any chosen competitor when defined for all the markets in which NTI operates. NTI has associated companies that provide GSM services in five countries and one region: Finland, Norway, Sweden, Denmark, Estonia and the St. Petersburg region.

We consider strategic decisions for the planning period 2004-2012. There are three possible alternatives for NTI: (i) introduction of third generation mobile solutions (3G); (ii) expanding its operations to other countries; and (iii) developing new m-commerce solutions. The introduction of a 3G system can be postponed by a maximum of two years, the expansion may be delayed by maximum of one year and the project on introduction of new m-commerce solutions should start immediately.

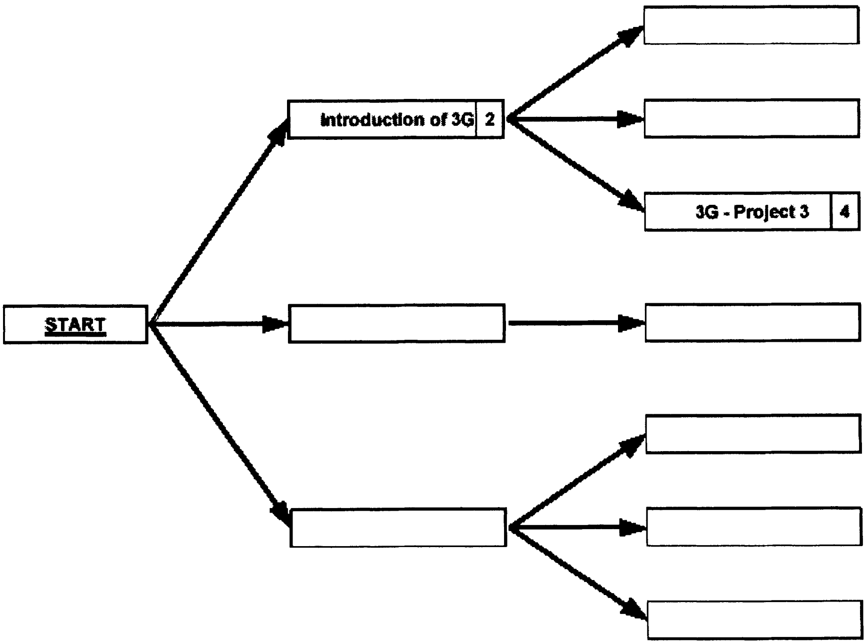


Figure 4.3. The optimal path.

Our goal is to maximize the company's cash flow at the end of the planning period (year 2012). In our computerized implementation we have represented NTI's strategic planning problem by a dynamic decision *tree, in which the future expected cash flows and costs are estimated by trapezoidal fuzzy numbers. Then using the theory of fuzzy real options we have computed the real option values for all nodes of the dynamic decision tree. Then we have selected the path with the biggest real option value in the end of the planning period (see Fig. 4.2 - Fig. 4.4).*

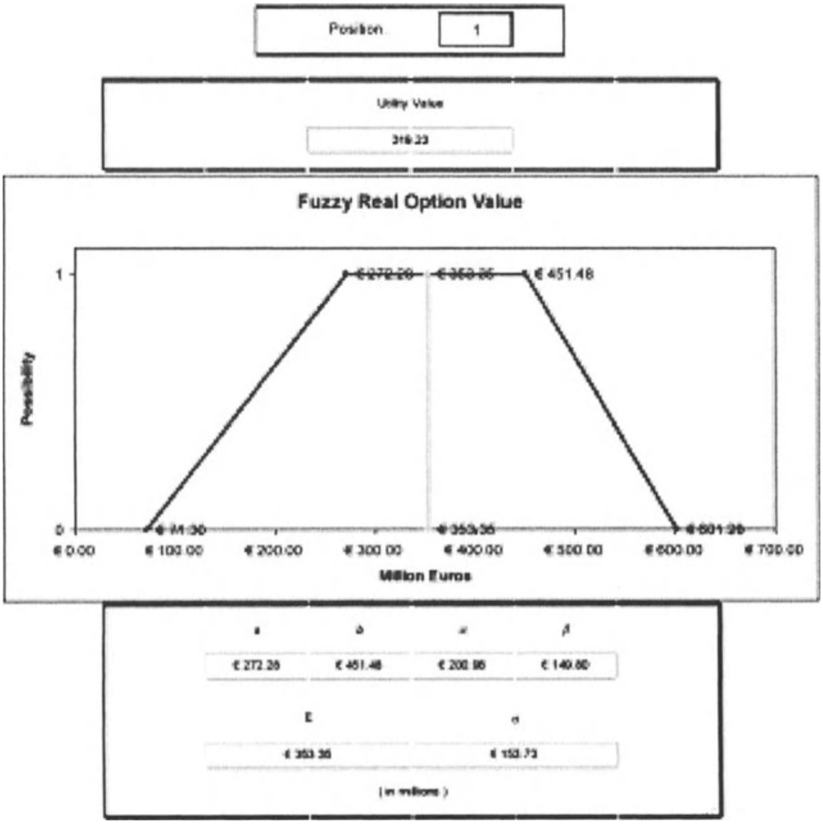


Figure 4.4. The fuzzy real option value.

3. Summary

Despite its appearance, the fuzzy real options model is quite practical and useful. Standard work in the field uses probability theory to account for the uncertainties involved in future cash flow estimates. This may be defended for financial options, for which we can assume the existence of an efficient market with numerous players and numerous stocks for trading, which may justify the assumption of the validity of the laws of large numbers and thus the use of probability theory. The situation for real options is quite different. The option to postpone an investment (which in our case is a very large *giga-investment*) will have consequences, differing from efficient markets, as the number of players producing the consequences is quite small.

The imprecision we encounter when judging or estimating future cash flows is not stochastic in nature, and the use of probability theory gives us a misleading level of precision and a notion that consequences somehow are repetitive. This is not the case, the uncertainty is genuine, i.e. we simply do not know the exact levels of future cash flows. Without introducing fuzzy real option models it would not be possible to formulate this genuine uncertainty. The proposed model that incorporates subjective judgments and statistical uncertainties may give investors a better understanding of the problem when making investment decisions.

References

[1] Alleman J. and Noam E. eds., *The New Investment Theory of Real Options and Its Implication for Telecommunications Economics*, Kluwer Academic Publishers, Boston 1999.

[2] Benaroch M. and Kauffman R.J., Justifying electronic banking network expansion using real options analysis, *MIS Quarterly*, 24(2000) 197-225.

[3] Balasubramanian P., Kulatikala N. and Storck J., Managing information technology investments using a real-options approach, *Journal of Strategic Information Systems*, 9(2000) 39-62.

[4] Black F. and Scholes M., The pricing of options and corporate liabilities, *Journal of Political Economy*, 81(1973) 637-659.

[5] Carlsson C. and Fullér R., Real option evaluation in fuzzy environment, in: *Proceedings of the International Symposium of Hungarian Researchers on Computational Intelligence*, Budapest, November 2, 2000 69-77.

[6] Carlsson C. and Fullér R., On possibilistic mean value and variance of fuzzy numbers, *Fuzzy Sets and Systems*, 122(2001) 315-326.

[7] Carlsson C., Fullér R. and Majlender P., Project selection with fuzzy real options, in: *Proceedings of the Second International Symposium of Hungarian Researchers on Computational Intelligence*, Budapest, November 12, 2001 81-88.

[8] Carlsson C. and Fullér R., On optimal investment timing with fuzzy real options, in: *Proceedings of the EUROFUSE 2001 Workshop on Preference Modelling and Applications*, April 25-28, 2001, Granada, Spain, 2001 235-239.

[9] Carlsson C. and Fullér R., Project scheduling with fuzzy real options, in: Robert Trappl ed., *Cybernetics and Systems '2002, Proceedings of the Sixteenth European Meeting on Cybernetics and Systems Research*, Vienna, April 2-4, 2002, Austrian Society for Cybernetic Studies, 2002 511-513.

[10] Carlsson C. and Fullér R., A fuzzy approach to real option valuation, *Fuzzy Sets and Systems* 139(2003) 297-312.

[11] Leslie K.J. and Michaels M.P., The real power of real options, *The McKinsey Quarterly*, 3(1997) 5-22.

[12] Luehrman T.A., Investment opportunities as real options: getting started on the numbers, *Harvard Business Review*, July-August 1998, 51-67.

[13] Merton R., Theory of rational option pricing, *Bell Journal of Economics and Management Science*, 4(1973) 141-183.

Chapter 5

A FUZZY APPROACH TO REDUCING THE BULLWHIP EFFECT

In this Chapter we will consider a series of companies in a supply chain, each of which orders from its immediate upstream collaborators. Usually, the retailer's order do not coincide with the actual retail sales. The *bullwhip effect* refers to the phenomenon where orders to the supplier tend to have larger variance than sales to the buyer (i.e. demand distortion), and the distortion propagates upstream in an amplified form (i.e. variance amplification). We show that if the members of the supply chain share information with intelligent support technology, and agree on better and better fuzzy estimates (as time advances) on future sales for the upcoming period, then the bullwhip effect can be significantly reduced.

The *Bullwhip Effect* has been the focus of theoretical work on and off during the last 20 years. However, the first papers reporting research findings in a more systematic fashion [8] have been published only recently. The effect was first identified in the 1980'es through the simulation experiment, *The Beer Game*, which demonstrated the effects of distorted information in the supply chain (which is one of the causes of the bullwhip effect).

A number of examples has been published which demonstrate the bullwhip effect, e.g. the Pampers case: (i) P & G has over the years been successful producers and sellers of Pampers, and they have seen that babies are reliable and steady consumers; (ii) the retailers in the region, however, show fluctuating sales, although the demand should be easy to estimate as soon as the number of babies in the region is known; (iii) P & G found out that the orders they received from distributors showed a strong variability, in fact much stronger than could be explained by the fluctuating sales of the retailers; finally, (iv) when P & G studied their own orders to 3M for raw material they found these to be wildly fluctuating, actually much more than could be explained by the orders from the distributors. Systematic studies of these fluctuations with the help of inventory models revealed the bullwhip effect.

The context we have chosen for this study is the forest products industry and the markets for fine paper products. The chain is thus a business-to-business supply chain, and we will show that the bullwhip effect is as dominant as in the business-to-consumer supply chain.

The key driver appears to be that the variability of the estimates or the forecasts of the demand for the paper products seems to amplify as the orders move up the supply chain from the printing houses, through the distributors and wholesalers to the producer of the paaper mills.

We found out that the bullwhip effect will have a number of negative effects in the paper products industry, and that it will cause significant inefficiencies:

1 Excessive inventory investments throughout the supply chain as printing houses, distributors, wholesalers, logistics operators and paper mills need to safeguard themselves against the variations.

2 Poor customer service as some part of the supply chain runs out of products due to the variability and insufficient means for coping with the variations.

3 Lost revenues due to shortages, which have been caused by the variations.

4 The productivity of invested capital in operations becomes substandard as revenues are lost.

5 Decision-makers react to the fluctuations in demand and make investment decisions or change capacity plans to meet peak demands. These decisions are probably misguided, as peak demands may be eliminated by reorganizations of the supply chain.

6 Demand variations cause variations in the logistics chain, which again cause fluctuations in the planned use of transportation capacity. This will again produce sub-optimal transportation schemes and increase transportation costs.

7 Demand fluctuations caused by the bullwhip effect may cause missed production schedules, which actually are completely unnecessary, as there are no real changes in the demand, only inefficiencies in the supply chain.

In two recent studies [8, 9], three more reasons have been identified to cause the bullwhip effect besides the demand forecasts: these include (i) order batching, (ii) price fluctuations and (iii) rationing and shortage gaming.

The *order batching* will appear in two different forms: (i) periodic ordering and (ii) push ordering. In the first case there is a number of reasons for building batches of individual orders. The costs for frequent order processing may be high, which will force customers into periodic ordering; this will in most cases destroy customer demand patterns. There are material requirement planning systems in use, which are run periodically and thus will cause that orders are placed periodically. Logistics operators often favor full truck load (FTL) batches and will determine their tariffs accordingly. These reasons for periodic ordering are quite rational, and will, when acted upon, amplify variability and contribute to the bullwhip effect. Push ordering occurs, as the sales people employed by the paper mills try to meet their end-of-quarter or end-of-year bonus plans. The effect of this is to amplify the variability with orders from customers overlapping end-of-quarter and beginning-of-quarter months, to destroy connections with the actual demand patterns of customers and to contribute to the bullwhip effect [8].

The paper mills initiate and control the *price fluctuations* for various reasons. Customers are driven to buy in larger quantities by attractive offers on quantity discounts, or price discounts. Their behavior is quite rational: to make the optimal use of opportunities when prices shift between high and low. The problem introduced by this behavior is that buying patterns will not reflect consumption patterns anymore, customers buy in quantities which do not reflect their needs. This will amplify the bullwhip effect. The consequences are that the paper mills (rightfully) suffer: manufacturing is on overtime during campaigns, premium transportation rates are paid during peak seasons and paper mills suffer damages in overflowing storage spaces [8].

The *rationing* and *shortage gaming* occurs when demand exceeds supply. If the paper mills once have met shortages with a rationing of customer deliveries, the customers will start to exaggerate their real needs when there is a fear that supply will not cover demand. The shortage of DRAM chips and the following strong fluctuations in demand was a historic case of the rationing and shortage game. The bullwhip effect will amplify even further if customers are allowed to cancel orders when their real demand is satisfied. The gaming leaves little information on real demand and will confuse the demand patterns of customers [8, 9]. On the other hand, there have not been any cases of shortage of production capacity of the paper products in the last decade; there is normally excess capacity. Thus we have excluded this possible cause from further study.

It is a fact that these four causes of the bullwhip effect may be hard to monitor, and even harder to control in the forest products industry. We should also be aware of the fact that the four causes may interact, and act in concert, and that the resulting combined effects are not clearly understood, neither in theory nor in practice. It is also probably the case that the four causes are dependent on the supply chain's infrastructure and on the strategies used by the various actors.

The factors driving the bullwhip effect appear to form a hyper-complex, i.e. a system where factors show complex interactive patterns. The theoretical challenges posed by a hyper-complex merit study, even if significant economic consequences would not have been involved. The costs incurred by the consequences of the bullwhip effect (estimated at 200-300 MFIM annually for a 300 kton paper mill) offer a few more reasons for carrying out serious work on the mechanisms driving the bullwhip.

Thus, we have built a theory to explain at least some of the factors and their interactions, and we have created a support system to come to terms with them and to find effective means to either reduce or eliminate the bullwhip effect.

With a little simplification there appears to be three possible approaches to counteract the bullwhip effect:

1 Find some means to share information from downstream the supply chain with all the preceding actors.

2 Build channel alignment with the help of some co-ordination of pricing, transportation, inventory planning and ownership - when this is not made illegal by anti-trust legislation.

3 Improve operational efficiency by reducing cost and by improving on lead times.

The first approach can probably be focused on finding some good information technology to accomplish the information sharing, as this can be shown to be beneficial for all the actors operating in the supply chain. We should probably implement some internet-based support technology for intelligent sharing of validated demand data.

The second approach can first be focused on some non-controversial element, such as the co-ordination of transportation or inventory planning, and then the alignment can be widened to explore possible interactions with other elements.

The third approach is probably straight-forward: find operational inefficiencies, then find ways to reduce costs and to improve on lead times, and thus explore if these solutions can be generalised for more actors in the supply chain.

The most effective - and the most challenging - effort will be to find ways to combine elements of all three approaches and to find synergistic programs to eliminate the bullwhip effect, which will have the added benefit of being very resource-effective.

1. The Bullwhip Effect, Some Additional Details

In 1998-99 we carried out a research program on the bullwhip effect with two major fine paper producers. The project, known as EM-S Bullwhip, worked with actual data and in interaction with senior decision makers. The two corporate members of the EM-S Bullwhip consortium had observed the bullwhip effects in their own markets and in their own supply chains for fine paper products. They also readily agreed that the bullwhip effect is causing problems and significant costs, and that any good theory or model, which could give some insight into dealing with the bullwhip effect, would be a worthwhile effort in terms of both time and resources.

Besides the generic reasons we introduced in the previous section, there are a few practical reasons why we get the bullwhip effect in the fine paper markets.

The first reason is to be found in the structure of the market (see Fig. 5.1).

The paper mills do not deal directly with their end-customers, the printing houses, but fine paper products are distributed through wholesalers, merchants and retailers. The paper mills may (i) own some of the operators in the market supply chain, (ii) they may share some of them with competitors or (iii) the operators may be completely independent and bound to play the market game with the paper producers. The operators in the market supply chain do not willingly share their customer and market data, information and knowledge with the paper mills.

Thus, the paper producers do not get *neither precise nor updated information* on the real customer demand, but get it in a filtered and/or manipulated way from the market supply chain operators. Market data is collected and summarized by independent data providers, and market forecasts are produced by professional forest products consultants and market study agencies, but it still appears that these macro level studies and forecasts do not apply exactly to the markets of a single paper producer. The market information needed for individual operations still needs to come from the individual market, and this information is not available to paper mills.

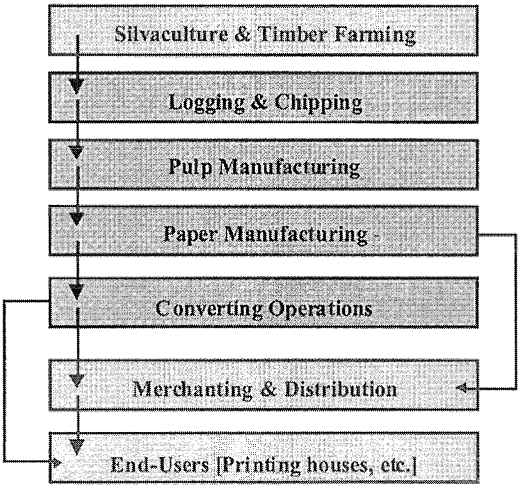


Figure 5.1. The supply chain of the market for fine paper products.

The second, more practical, reason for the bullwhip effect to occur is found earlier in the supply chain. The demand and price fluctuations of the pulp markets dominate also the demand and price patterns of the paper products markets, even to such an extent, that the customers for paper products anticipate the expectations on changes in the pulp markets and act accordingly. If pulp prices decline, or are expected to decline, demand for paper products will decline, or stop in anticipation of price reductions. Then, eventually, prices will in fact go down as the demand has disappeared and the paper producers get nervous. The initial reason for fluctuations in the pulp market may be purely speculative, or may have no reason at all. Thus, the construction of any reasonable, explanatory cause-effect relationships to find out the market mechanisms that drive the bullwhip may be futile. If we want to draw an even more complex picture we could include the interplay of the operators in the market supply chain: their anticipations of the reactions of the other operators and their individual, rational (possibly even optimal) strategies to decide how to operate. This is a later task, to work out a *composite bullwhip effect* among the market supply chain operators, as we cannot deal with this more complex aspect here.

The third practical reason for the bullwhip effect is specialized form of order batching. The logistics systems for paper products favor shiploads of paper products, the building of inventories in the supply chain to meet demand fluctuations and push ordering to meet end-of-quarter or end-of-year financial needs. The logistics operators are quite often independent of both the paper mills and the wholesalers and/or retailers, which will make them want to operate with optimal programs in order to meet their financial goals. Thus they decide their own tariffs in such a way that their operations are effective and profitable, which will - in turn - affect the decisions of the market supply chain operators, including the paper producers. The adjustment to proper shipload or FTL batches will drive the bullwhip effect.

There is a fourth practical reason, which is caused by the paper producers themselves. There are attempts at influencing or controlling the paper products markets by having occasional low price campaigns or special offers. The market supply chain operators react by speculating in the timing and the level of low price offers and will use the (rational) policy of buying only at low prices for a while. This normally triggers the bullwhip effect.

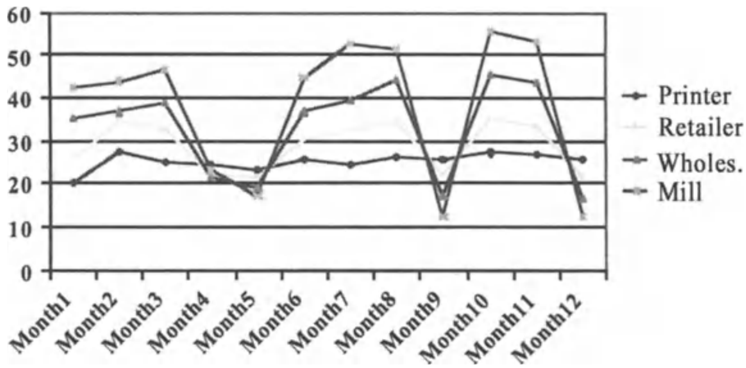


Figure 5.2. The bullwhip effect in the fine paper products market.

The bullwhip effect may be illustrated as in Fig. 5.2 The variations shown in Fig. 5.2 are simplifications, but the following patterns appear: (i) the printer (an end-customer) orders once per quarter according to the real market demand he has or is estimating; (ii) the dealer meets this demand and anticipates that the printer may need more (or less) than he orders; the dealer acts somewhat later than his customer; (iii) the paper mill reacts to the dealer's orders in the same fashion and somewhat later than the dealer. The resulting overall effect is the bullwhip effect.

In the following section, we will present the standard theory for explaining the bullwhip and for coming to terms with it.

1.1 Explanations for the Bullwhip Effect

Lee et al [8, 9] focus their study on the demand information flow and worked out a theoretical framework for studying the effects of systematic information distortion as information works its way through the supply chain. They simplify the context for their theoretical work by defining an idealised situation. They start with a multiple period inventory system, which is operated under a periodic review policy. They include the following assumptions: (i) past demands are not used for forecasting, (ii) re-supply is infinite with a fixed lead time, (iii) there is no fixed order cost, and (iv) purchase cost of the product is stationary over time. If the demand is stationary, the standard optimal result for this type of inventory system is to order up to S, where S is a constant. The optimal order quantity in each period is exactly equal to the demand of the previous period, which means that orders and demand have the same variance (and there is no bullwhip effect).

This idealized situation is useful as a starting point, as is gives a good basis for working out the consequences of distortion of information in terms of the variance, which is the indicator of the bullwhip effect. By relaxing the assumptions (i)-(iv), one at a time, it is possible to produce the bullwhip effect.

1.2 Demand Signal Processing

Let us focus on the retailer-wholesaler relationship in the fine paper products market (the framework applies also to a wholesaler-distributor or distributor-producer relationship). Now we consider a multiple period inventory model where demand is non-stationary over time and demand forecasts are updated from observed demand.

Lets assume that the retailer gets a much higher demand in one period. This will be interpreted as a signal for higher demand in the future, the demand forecasts for future periods get adjusted, and the retailer reacts by placing a larger order with the wholesaler. As the demand is non-stationary, the optimal policy of ordering up to S also gets non-stationary. A further consequence is that the variance of the orders grows, which is starting the bullwhip effect. If the lead-time between ordering point and the point of delivery is long, uncertainty increases and the retailer adds a "safety margin" to S, which will further increase the variance - and add to the bullwhip effect.

Lee et al simplify the context even further by focusing on a single-item, multiple period inventory, in order to be able to work out the exact bullwhip model.

The timing of the events is as follows: At the beginning of period t, a decision to order a quantity z_t is made. This time point is called the "decision point" for period t. Next the goods ordered ν periods ago arrive. Lastly, demand is realized, and the available inventory is used to meet the demand. Excess demand is backlogged. Let S_t denote the amount in stock plus on order (including those in transit) after decision z_t has been made for period t. Lee at al [8] assume that the retailer faces serially correlated demands which follow the process

$$D_t = d + \rho D_{t-1} + u_t$$

where D_t is the demand in period t, ρ is a constant satisfying $-1 < \rho < 1$, and u_t is independent and identically normally distibuted with zero mean and variance σ^2. Here σ^2 is assumed to be significantly smaller than d, so that the probability of a negative demand is very small. The existence of d, which is some constant, basic demand, is doubtful; in the forest products markets a producer cannot expect to have any "granted demand". The use of d is technical, to avoid negative demand, which will destroy the model, and it does not appear in the optimal order quantity. Lee et al proved the following theorem,

Theorem 5.1. [8] *In the above setting, we have,*

1 *If* $0 < \rho < 1$, *the variance of retails orders is strictly larger than that of retail sales; that is,* $\mathrm{Var}(z_1) > \mathrm{Var}(D_0)$.

2 *If* $0 < \rho < 1$, *the larger the replenishment lead time, the larger the variance of orders; i.e.* $\mathrm{Var}(z_1)$ *is strictly increasing in* ν.

This theorem has been proved from the relationships

$$z_1^* = S_1 - S_0 + D_0 = \frac{\rho(1-\rho^{\nu+1})}{1-\rho}(D_0 - D_{-1}) + D_0, \tag{5.1}$$

and

$$\mathrm{Var}(z_1^*) = \mathrm{Var}(D_0) + \frac{2\rho(1-\rho^{\nu+1})(1-\rho^{\nu+2})}{(1+\rho)(1-\rho)^2} > \mathrm{Var}(D_0),$$

where z_1^* denotes the optimal amount of order. Which collapses into

$$\mathrm{Var}(z_1^*) = \mathrm{Var}(D_0) + 2\rho,$$

for $\nu = 0$.

The optimal order quantity is an optimal ordering policy, which sheds some new light on the bullwhip effect. The effect gets started by rational decision making, i.e. by decision makers doing the best they can. In other words, there is no hope to avoid the bullwhip effect by changing the ordering policy, as it is difficult to motivate people to act in an irrational way. Other means will be necessary.

It appears obvious that the paper mill could counteract the bullwhip effect by forming an alliance with either the retailers or the end-customers. The paper mill could, for instance, provide them with forecasting tools and build a network in order to continuously update market demand forecasts. This is, however, not allowed by the wholesalers.

1.3 Order Batching

In order to study this cause for the bullwhip effect we need to change the context. Consider an inventory system with periodic reviews and full backlogging at a retailer. Let us assume that the demand is stationary, in which case the optimal order policy is to order up to S, which is equal to the previous review cycle's demand in every review cycle. Let us further assume that we have n retailers, all of which use a periodic review system with a review cycle of r periods, and that each retailer faces a demand pattern with mean m and variance σ^2.

Let us then focus on the wholesaler. From his perspective he has n retailers acting together through (i) random ordering, (ii) (positively) correlated ordering and (iii) balanced ordering, and it is evident that the use of his production capacity will be affected by the ordering patterns of the retailers. If all the retailers need to get their deliveries at exactly the same time, his delivery will run differently as compared to deliveries taking place uniformly in the order/production/delivery cycle.

Lee et al [8] show that with random ordering, each retailer appears with an order randomly during the cycle, the demand variance as seen by the wholesaler is the same as the demand variance seen by the retailer, if the review cycle $r = 1$. If the review cycle is longer, the wholesaler's demand variance will always be larger and the bullwhip effect gets initiated.

In the case of (positively) correlated ordering, we have an extreme situation, that all retailers order at exactly the same instance of the review cycle r. Lee et al [8] show that the resulting variance is much larger than the variance for random ordering. This is quite understandable, as the wholesaler will have ordering peaks on (for instance) one day and nothing during the rest of the review cycle. If ordering and delivery policies are negotiated with retailers, a wholesaler should take care to avoid a situation where the retailers find it beneficial to use positively correlated ordering, as it for sure will drive the bullwhip effect.

The ideal case is one in which the retailers order in a way, which is evenly distributed in the review cycle r. In order for this to happen, the wholesaler needs a co-ordination scheme in which the retailers are organized in groups. Then all retailers in the same group order in a designated period within the review cycle r, and no other group orders in the same period.

Lee et al [8] show that this scheme gives the wholesaler the smallest variance. This is reasonable, because the wholesaler can use his resources evenly during the review cycle and can estimate the order quantities to come in from each group.

Thus, different ordering patterns generate different variances in the review period. *Correlated ordering* with all orders appearing at the same instance shows the largest variance. *Balanced ordering* with all orders perfectly coordinated shows the lowest variance, and the *random ordering* falls in between the two other patterns. In all cases Lee et al was able to prove, that the variance experienced by the wholesaler was larger than the variance of any chosen retailer, which shows that the bullwhip effect is present with all three ordering patterns.

The ordering pattern models can be extended to a three-layer supply chain: retailer, wholesaler and producer, in which case we get combinations of ordering patterns as the wholesaler would not necessarily use the same ordering pattern as his retailers. The variance the producer experiences will in most cases be larger than the variance seen by the wholesaler. Rational decision making will force the wholesaler to replicate and amplify the variance he is getting from the retailers with his producer.

There is an ideal case, in which the bullwhip effect can be eliminated. If the wholesaler can get his retailers to form one single group for the review cycle, and then can persuade them to agree on their total orders m (as well as agreeing among themselves. how to share this total amount) then there will be no bullwhip effect. Such a case is a bit hard to find in the forest products markets, as the EU would not look kindly on attempts of this kind to limit competition.

1.4 Price Variations

Let us change context one more time. We will assume that a retailer faces an independent demand $\Phi(\cdot)$ for each period (but identically distributed for all periods). The wholesaler, the only source for the retailer, alternates between two prices c^L and c^H over time. The retailer perceives that the alternating is random with probabilities q and $(1-q)$ for c^L and c^H respectively.

Lee et al [8] show that the optimal ordering policy for the retailer is to determine two ordering levels, S^L for c^L and S^H for c^H. Then, as the price is low order as much as possible (i.e. S^L) and as the price is high order as little as possible (i.e. S^H) or nothing at all. It is clear that this will drive the bullwhip effect, as it is an optimal policy for the retailer to allow the orders to fluctuate with the price variations. It can be shown that even anticipated price variations will introduce the bullwhip effect as it is an optimal policy to adapt orders to anticipated price variations.

If we extend the price variations to more layers of the supply chain and include the producer, it is clear that the price variations reflected by the wholesaler have their origins with the producer. It would be an extreme, speculative case if the wholesaler could generate price variations on his own. Thus, the producer will face an optimal ordering policy from the wholesaler and find out that he gets orders only when he is offering the low price c^L. The variance faced by the wholesaler gets amplified as it is passed to the producer and the bullwhip effect seen by the producer is much stronger.

Inversely, it is possible to argue that if the producer refrains from price variations, and declares this policy publicly, then the bullwhip effect could be significantly reduced as the retailers would not allow the wholesalers to introduce any significant price variations. In the forest products market this would be possible but for the price variations forced by the strongly varying pulp prices, which seem to follow a logic of their own and which appears to be very difficult to forecast.

As the optimal, crisp ordering policy drives the bullwhip effect we decided to try a policy in which orders are imprecise. This means that orders can be intervals, and we will allow the actors in the supply chain to make their orders more precise as the (time) point of delivery gets closer. We can work out such a policy by replacing the crisp orders by fuzzy numbers.

2. Fuzzy Approaches to Demand Signal Processing

Following Carlsson and Fullér [1, 2, 3, 4, 5, 6] we will carry this out only for the demand signal processing case. It should be noted, however, that the proposed procedure can be applied also to the price variations module and - with some more modeling efforts - to the cases with the rationing game and order batching.

Let us consider equation (5.1) with trapezoidal fuzzy numbers

$$z_1^* = S_1 - S_0 + D_0 = \frac{\rho(1-\rho^{\nu+1})}{1-\rho}(D_0 - D_{-1}) + D_0. \qquad (5.2)$$

Then from Theorem 2.1 we get

$$\text{Var}(z_1^*) > \text{Var}(D_0),$$

so the simple adaptation of the probabilistic model (i.e. the replacement of probabilistic distributions by possibilistic ones) does not reduce the bullwhip effect.

We will show, however that by including better and better estimates of future sales in period one, D_1, we can reduce the variance of z_1 by replacing the old rule for ordering (5.2) with an adjusted rule.

If the participants of the supply chain do not share information, or they do not agree on the value of D_1 then we can apply a neural fuzzy system that uses an error correction learning procedure to predict z_1. This system should include historical data, and a supervisor who is in the position to derive some initial linguistic rules from past situations which would have reduced the bullwhip effect.

A typical fuzzy logic controller (FLC) describes the relationship between the change of the control $\Delta u(t) = u(t) - u(t-1)$ on the one hand, and the error $e(t)$ (the difference between the desired and computed system output) and its change

$$\Delta e(t) = e(t) - e(t-1).$$

on the other hand. The actual output of the controller $u(t)$ is obtained from the previous value of control $u(t-1)$ that is updated by $\Delta u(t)$. This type of controller was suggested originally by Mamdani and Assilian in 1975 and is called the *Mamdani-type* FLC [10].

A prototype rule-base of a simple FLC, which is realized with three linguistic values {N: negative, ZE: zero, P: positive} is listed in Table 5.1. To reduce the bullwhip effect we suggest the use of a fuzzy logic controller. Demand realizations D_{t-1} and D_{t-2} denote the volumes of retail sales in periods $t-1$ and $t-2$, respectively. We use a FLC to determine the change in *order*, denoted by Δz_1, in order to reduce the bullwhip effect, that is, the variance of z_1.

We shall derive z_1 from D_0, D_{-1} (sales data in the last two periods) and from the last order z_0 as

$$z_1 = z_0 + \Delta z_1$$

where the crisp value of Δz_1 is derived from the rule base $\{\Re_1, \dots, \Re_5\}$, where $e = D_0 - z_0$ is the difference between the past realized demand

Table 5.1. A Mamdani-type FLC in a tabular form.

$\Delta e(t) \mid e(t) \rightarrow$ $\downarrow$	N	ZE	P
N	N	N	ZE
ZE	N	ZE	P
P	ZE	P	P

(sales), D_0 and order z_0, and the change of error

$$\Delta e := e - e_{-1} = (D_0 - z_0) - (D_{-1} - z_{-1}),$$

is the change between $(D_0 - z_0)$ and $(D_{-1} - z_{-1})$.

To improve the performance (approximation ability) we can include more historical data D_{t-3}, $D_{t-4} \ldots$, in the antecedent part of the rules. The problem is that the fuzzy system itself can not learn the membership function of Δz_1, so we could include a neural network to approximate the crisp value of z_1, which is the most typical value of $z_0 + \Delta z_1$.

It is here, that the supervisor should provide crisp historical learning patterns for the concrete problem, for example,

$$\{5, 30, 20\}$$

which tells us that if at some past situations $(D_{k-2} - z_{k-2})$ was 5 and $(D_{k-1} - z_{k-1})$ was 30 then then the value of z_k should have been $(z_{k-1} + 20)$ in order to reduce the bullwhip effect.

The meaning of this pattern can be interpreted as: if the preceding chain member ordered a little bit less than he sold in period $(k-2)$ and much less in period $(k-1)$ then his order for period k should have been enlarged by 20 in order to reduce the bullwhip effect (otherwise - at a later time - the order from this member would unexpectedly jump in order to meet his customers' demand - and that is the bullwhip effect).

Then the output of the neural fuzzy numbers is computed as the most typical value of the fuzzy system, and the system parameters (i.e. the shape functions of the error, change in error and change in order) are learned by the generalized δ learning rule (the error back propagation algorithm).

3. A Hybrid Soft Computing Platform for Taming the Bullwhip Effect

Having understood the core elements of the bullwhip effect and the mechanisms, which drive it, the next challenge is to create instruments to deal with it. Our first step was to build a platform for experimenting with the drivers of the bullwhip effect and for testing our understanding of how to reduce or eliminate the effect.

This platform is one in the series of hyperknowledge platforms, which have been developed by IAMSR in the last 6-7 years. The platform shown in fig. 6.12 is a prototype, which was built mainly to validate and to verify the theory we have developed for coping with the bullwhip effect - a more advanced platform is forthcoming, as the work with finding new ways to tame the bullwhip effect continues in other industries than the fine paper products.

The platform is built in Java 2.0 and it was designed to operate over the Internet or through a corporate intranet. This makes it possible for a user to work with the bullwhip effect as (i) part of a corporate strategic planning session, as (ii) part of a negotiation program with retailers and/or wholesalers, as (iii) part of finding better ECR solutions when dealing with end customers, as (iv) support for negotiating with transport companies and logistics subcontractors, and as (v) a basis for finding new solutions when organizing the supply chain for the end customers. In the future, we believe that some parts of the platform could be operated with mobile, WAP-like devices.

The platform includes the following elements (Fig. 5.3):

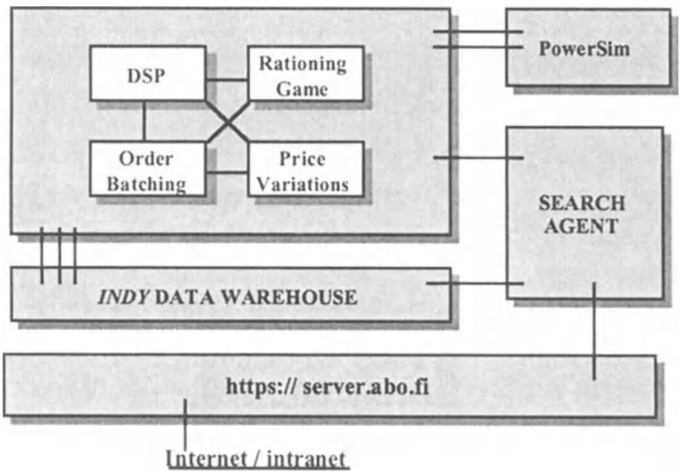


Figure 5.3. A soft computing platform.

The platform is operated on a secure server, which was built at IAMSR in order to include some non-standard safety features.

There are four models operated on the platform: (i) *DSP* for demand signal processing, (ii) *Rationing Game* for handling the optimal strategies as demand exceeds supply and the deliveries have to be rationed, (iii) *Order Batching* for working out optimal delivery schemes when there are constraints like *full shipload*, and (iv) *Price Variations* for working out the best pricing policies when the paper mill wants to shift between low and high prices.

The hyperknowledge features allow the models to be in-terconnected, which means that the effects of the DSP can be taken as input when working out either Order Batching or Price Variations effects. Thus, models can be operated either individually or as cause-effect chains.

Data for the models is collected with search agents, which operate on either databases in the corporate intranet or on data sources in the Internet. Also the search agents have been designed, built in Java and implemented for corporate partners by IAMSR as part of a series of research programs. The agents can be used to feed the models directly or to organize the data as input formats (e.g. as spreadsheets) tailored to the models and stored in a data warehouse. The INDY application used for the platform is a spreadsheet-oriented data warehouse with intelligent support for import and export of data.

As part of the experimental platform we have also included support for the PowerSim package, which makes it possible to carry out *systems dynamics*-type simulations of possible action programs as these change and adapt to changing data.

After experimenting with the platform we summarized our findings in the following *macro-algorithm for taming the bullwhip effect*:

1 Demand Signal Processing.

1.1 *Information on true demand can be shared throughout the supply chain.*

1.1.1 Establish a secure Internet portal for the supply chain actors.

1.1.2 Make forecasting tools available and request that all actors use them.

1.1.3 Post and update forecasts of actual demand.

1.1.4 Support negotiations of actual deliveries with updates of changes in demand; search agents used to scan relevant data sources for data, which can be used for updating forecasts.

1.2 *Information on true demand cannot be shared throughout the supply chain.*

1.2.1 Establish an internal ordering policy and negotiate for all the supply chain actors to participate.

1.2.2 Make the DSP models available to all the actors and allow them to work out optimal ordering policies.

1.2.3 Actors are allowed to monitor the supply chain inventories through the hyperknowledge platform (voluntary information, which is evaluated against optimal inventory policies).

1.2.4 Actors can elect to use the DSP models or not.

2 Price variations.

2.1 *Start from the ordering policies derived with the DSP.*

2.1.1 Find and negotiate a stable pricing policy for all the actors; implement this and eliminate the bullwhip effect.

2.2 *A stable pricing policy cannot be agreed upon (there may be, for instance, significant changes in the pulp prices.*

2.2.1 Use the fuzzy numbers model to determine good price intervals.

2.2.2 Make the Price Variations models available to all the actors and allow them to work out optimal ordering policies.

2.2.3 Actors are allowed to monitor the supply chain inventories through the hyperknowledge platform (voluntary information, which is evaluated against optimal inventory policies).

2.2.4 Actors can elect to use the Price Variations models or not.

3 Order Batching.

3.1 Start from the ordering policies derived with the DSP.

3.2 The paper mill will negotiate optimal production batches with the whole-salers (and retailers and end-customers if possible; normally the wholesalers do not give access to the parts of the supply chain they control) and reacts to demand variations with an AR scheme of the type discussed above.

3.3 If the negotiations are not possible due to partisan interests, each actor will decide on the order batching individually.

3.3.1 The Order Batching model is an AR scheme, which allows each actor to find a flexible scheme for order batching.

3.3.2 Make the Order Batching models available to all the actors and allow them to work out optimal ordering policies.

3.3.3 Actors are allowed to monitor the supply chain inventories through the hyperknowledge platform (voluntary information, which is evaluated against optimal inventory policies).

3.3.4 Actors can elect to use the Order Batching models or not.

4 Rationing Game.

4.1 For the last decade rationing has not been necessary in the fine paper markets, as there is a stable overcapacity available due to excessive investments in (very) large paper mills.

4.2 The Nash equilibrium model with fuzzy numbers is a challenge still to be faced.

All steps of the macro algorithm can and should be supported with the hyperknowledge platform, which will help to coordinate and work out action programs. The programs will either reduce or eliminate the bullwhip effect.

The compound effects of multiple bullwhip effects are complex and represent topics for future research.

In summary, the macro algorithm offers some first possibilities to come to terms with the bullwhip effect, which appears to be made worse with the use of stochastic models. The random factors used by Lee at al [8] actually increase the variance (and the bullwhip effect) as the optimal solutions offered incorporate random factors and crisp policies - and this will produce a 'bang-bang' effect of shifting between optimally small and large orders.

4. Summary

The results reached in the EM-S Bullwhip project are mainly theoretical results, which also was the goal and the aim for the research program. Nevertheless, many of the results we have found in working with both the standard Lee et al model and with the new EM-S Bullwhip model have practical implications. Even if we propose them as "ways to handle the bullwhip effect for paper mills", it should be clear that significant validation and verification work remains to be done before this statement will be fully true. The validation and verification process requires access to specific data on real market operations, preferably on the paper mill level.

As a tool for the verification and validation process, we built a prototype of a decision support system in which we have implemented causal models, which describe the four bullwhip-driving factors. The system is a platform for testing different policy solutions with the bullwhip models, for collecting data from different data sources with intelligent agents, which also update the models, and for running simulations of the processes involved with the PowerSim software package.

Nevertheless, quite some work is needed for re-engineering the logistics chain and getting its operators to agree on sharing information. This is essential, as we can hope to eliminate the bullwhip effect only to some degree if we have to keep estimating the activities of the supply chain operators.

If this negotiating process gets complex and time-consuming, a business unit can still work with the bullwhip effect internally by following up on its demand and sales patterns, and by trying to find ways to neutralize the most violent variations. For this purpose, the mathematical results we have found will be most useful. This work can be combined with running experiments with different solutions with the help of the PowerSim models.

References

[1] Carlsson C. and Fullér R., Soft computing and the bullwhip effect, *Economics and Complexity*, Vol. 2, No. 3, Winter 1999-2000 1-26.

[2] Carlsson C. and Fullér R., A fuzzy approach to taming the bullwhip effect, in: *Proceedings of the Symposium on Computational Intelligence and Learning, (CoIL'2000)*, Chios, Greece, June 22-23, 2000 42-49.

[3] Carlsson C. and Fullér R., A fuzzy approach to the bullwhip effect, *Cybernetics and Systems '2000, Proceedings of the Fifteenth European Meeting on Cybernetics and Systems Research*, Vienna, April 25 - 28, 2000, Austrian Society for Cybernetic Studies, 2000 228-233

[4] Carlsson C. and Fullér R., On possibilistic mean value and variance of fuzzy numbers, *Fuzzy Sets and Systems*, 122(2001) 315-326.

[5] Carlsson C. and Fullér R., Reducing the bullwhip effec by means of intelligent, soft computing methods, in: *Proceedings of the 34-th Hawaii International Conference on System Sciences (HICSS-34)*, Island of Maui, Hawaii, USA, January 3-6, 2001, 10 pages.

[6] Carlsson C. and Fullér R., A fuzzy approach to taming the bullwhip effect, in: H.-J. Zimmermann, G. Tselentis, M. van Someren and G. Dounias eds., *Advances in Computational Intelligence and Learning, Methods and Applications*, Kluwer Academic Publishers, Boston, 2002 247-262.

[7] Heyman D. and Sobel M., *Stochastic Models in Operations Research*, vol. I, McGraw-Hill, New York, 1984.

[8] Lee H.L., Padmanabhan V. and Whang S., Information distortion in a supply chain: The bullwhip effect, *Management Science*, 43(1997) 546-558.

[9] Lee H.L., Padmanabhan V. and Whang S., The Bullwhip Effect in Supply Chains, *Sloan Management Review*, Spring 1997 93-102.

[10] Mamdani E.H. and Assilian S., An experiment in linquistic synthesis with a fuzzy logic controller. *International Journal of Man-Machine Studies* 7(1975) 1-13.

Chapter 6

KNOWLEDGE MANAGEMENT

1. Introduction

Professor Lotfi Zadeh, the founder of the fuzzy logic paradigm, has neatly summarized the main issues in sense-making in an interview more than 10 years ago (cf [14]). In the following we will work through his main points and try to identify their implications for knowledge management and a possible use of agent technology to make knowledge management easier to handle and more effective in implementation.

Let us start with the problem of *summarization*, which intuitively is part of most knowledge management efforts. Zadeh mentions that progress has been made on summarizing stereotypical stories by researchers at the Yale University (Roger Schank and co-workers). A good example of a stereotypical story, says Zadeh, is a report on an automobile accident: there is an indication of what kind of accident it was, when it occurred, where it occurred, the vehicles involved, whether there were injuries, the type of injuries, etc. A stereotypical story has a predetermined structure and if we have a predetermined structure, then we can understand a story and summarize it.

Even at this moment, it is very difficult and often impossible to write software to summarize a story because the ability to summarize requires an ability to understand the essence of the material. Some of the software packages for knowledge management actually mentions a capability at summarizing but a closer study shows that the actual process is collecting some number of lines from an abstract or an introductory summary of a document. Our studies of the use of agents for foresights, on the other hand, show that a true summary of the potential development of future events is something for professionals as it is a test of intelligence

C. Carlsson et al., *Fuzzy Logic in Management*

and competence. Suppose we asked a person not familiar with mathematics to summarize a paper on mcdm, real options theory, possibility theory, etc. in a mathematical journal. It would be impossible for him to summarize it, because he does not understand what the paper is about, what the results are, what the significance is - or even worse, he may actually summarize it and in the process will miss most of the contributions and the finer points made on the theory and its application. This is also known as popularization (or in some cases even "fuzzification"), a disease which appears to cling to the development and the use of fuzzy logic and fuzzy sets theory and applications.

With summarization we work towards getting software, which can help us with *interpretation* and to *make sense* of knowledge material.

A key to interpretation is the ability to arrive at *assessments.* We are good at making assessments of age just by looking at a person: all of us can see the distinctions between someone 70 years old and someone 5 years old; a 20 year old quickly makes distinctions between somebody 16 years old and 20 years old, which is harder for somebody 40 years old. Our points of reference for making assessments tend to shift with our own context. At this point, it is a tough challenge to write software, which would be capable of making assessments of this kind. The key is that we cannot articulate too well the rules we employ subconsciously to assess a person's age.

Another key part of interpretation is *reasoning.* In this chapter we will work with agents, and we should make the point that agents are artificial intelligence (AI) constructs and follow the tradition built in AI over more than four decades. The conservative AI approach is built around first order logic (an example of first order logic is the classical scheme: "all men are mortal; Socrates is a man; therefore Socrates is mortal"). Zadeh points to an opposition against this conservative approach, which claims that logic is of limited or no relevance to AI (Roger Schank (Yale University), Marvin Minsky (MIT)). They believe that first order logic is too limited to be able to deal effectively with the complexity of human cognitive processes. Instead of systematic, logical methods, this second camp relies on the use of ad hoc techniques and heuristic procedures.

Fuzzy logic and approximate reasoning is forming a third camp within AI. Zadeh maintains that we need logic in AI constructs, but the logic needed is not first-order logic but fuzzy logic, which underlies inexact or approximate reasoning. Most human reasoning is imprecise and much of it is what we might call common sense reasoning for which first-order logic is much too precise and much too confining to offer a good conceptual and methodological basis. The multi-valued logic systems are sometimes offered as alternatives to the first-order logic, but they have not been used to any significant extent in linguistics, in psychology or in other fields where human cognition plays an important role. Zadeh maintains that the reason is that they do not go far enough, that they do not capture the reasoning we need to work with human cognition. This is where fuzzy logic has become useful.

As wee have seen in previous chapters, in fuzzy logic we can deal with fuzzy quantifiers like *most*, *few*, *many* and *several.* Fuzzy quantifiers deal with fuzzy enumeration, which gives an imprecise or approximate count. In the real world we could identify an infinite number of fuzzy quantifiers as there is an infinite number of ways to count objects in an approximate fashion. In fuzzy logic it is the case that *truth* itself can be a fuzzy concept, i.e. we can use classifications such as *quite true* or *more or less true* in the statements. We can also use fuzzy probabilities like *not very likely*, *almost impossible* or *rarely.* In this way, fuzzy logic builds a system, which at least shows some promise to be sufficiently flexible and expressive to serve as a framework for knowledge management if we need to make use of the semantics of natural languages.

Furthermore, fuzzy logic can serve as a basis for reasoning with common sense knowledge, for pattern recognition, decision analysis, etc - application areas in which the underlying information is imprecise. The ability of the human mind to reason in something close to fuzzy terms (in the sense we briefly outlined above) is actually a great advantage. Even if a huge amount of information is presented to the human senses in a given situation, somehow the human mind has the ability to discard most of this information and to concentrate only on the information that is task relevant. This capability is hunted for in the software designs for knowledge management, and if it can be found the software systems will have the capability of summarizing, and then as an extension when further enhanced the capability of interpretation.

In the following we will summarize parts of a fairly complete study of the state-of-the-art of knowledge management and discuss how software agents can be used as supporting software in an attempt to identify the potential for implementations of fuzzy logic based constructs.

2. The Current Stage of Knowledge Management Research

Knowledge has always been considered a valuable asset in organizations. However, with organizations increasingly exposed to global competition many argue that knowledge has become the most critical asset for organizations (Davenport & Prusak, 1998). Thus, it becomes essential to understand how to develop knowledge at the individual, group and organization level, how to improve approaches to knowledge transfer, and how to realize effective knowledge deployment and management.

Viewing organizations as knowledge systems has turned out to be a very fruitful, i.e. if an organization is a collection of knowledge assets then the refinement, the updating and the management of those assets is of high importance. Thus, the current emphasis is on attempts to understand knowledge creation, transmission, storage and retrieval. Since knowledge assets are central to both the operations and the management of a company, the ways in which companies develop and sustain their knowledge-based capabilities is an interesting and relevant topic.

The growing field (and business for consultants) known as knowledge management (KM) has attracted a lot of attention in both research and practice over the last 10-15 years. One of the main drivers of KM is information technology. The general assumption behind quite a few KM initiatives is that IT can positively affect knowledge sharing across organization. Knowledge is seen as one of the key assets of the company and the main source of its competitive advantage.

Practitioners, and particularly consultants, are using KM as a management, marketing and image-building concept, because "...there's money to be made selling software, systems, and consulting services with the touted goal of allowing every person in an organization to be able to lay his hands on the collected know-how, experience, and wisdom of all his colleagues" (Stewart, 2002).

Knowledge management is an accepted part of the business agenda. In the year 2000 KPMG Consulting[1] conducted a survey among 423 organizations in the UK, Europe and the US. This survey gives a good picture of KM projects in companies over the world. Thus we may expect it to provide us with some guidance on how to tackle the issues and where to expect the challenges.

Over four fifths (81%) said they had a (KM) program, or were considering, a KM program. Companies were looking to KM to play an "extremely significant" or a "significant" role in improving competitive advantage (79%), in marketing (75%), in improving customer focus (72%), employee development (57%), product innovation (64%) and revenue growth and profit (both 63%).

The respondents' experience was that KM does provide real benefits. For example, almost three-quarters (71%) of those with a KM program in place said they had achieved better decision making, 68% said they

[1] In September, 2002 KPMG Consulting was renamed to Bearpoint Inc.

had achieved faster response to key business issues and 64% said they had delivered better customer service.

Organizations may be missing the longer-term financial benefits. Three times as many respondents expected their KM program to lead to increased profits (76%) and reduced costs (73%) as expected it to lead to an increase in their company's share price (28%). They see the immediate, internal cost gains but fail to equate these to any external, longer term benefit, such as intellectual capital growth. Although it is useful to concentrate on profits and costs of other internal factors, companies should also understand they can benefit in other ways such as share price growth.

It is important to understand the factors affecting success or failure of a KM effort. From 36% of those who said that KM failed to meet the expectations the following reasons for failure have been found:

- lack of user uptake owing to insufficient communication (20%)
- failure to integrate KM into everyday working practices (19%)
- lack of time to learn how to use the system or a sense that the system was too complicated (18%)
- lack of training (15%)
- a sense that there was little personal benefit in it for the user (13%)
- the lack of time to share knowledge (62%)
- failure to use knowledge effectively (57%), and
- the difficulty of capturing tacit knowledge (50%)

These problems reflect organizations' failure to grasp the cultural implications of KM. Fewer than one in five of all respondents had created a knowledge map (18%) - a catalogue or guide showing employees what information is available. This might explain why nearly two-thirds (65%) of organizations with a KM program complained of information overload - the creation of a knowledge glut or an overwhelming collection of information for information's sake that can be difficult and laborious to use.

Companies often see knowledge management as a purely technological solution. Organizations have adopted a number of relevant technologies for KM purposes. 93% of the respondents used the Internet to access external knowledge, 78% used an intranet, 63% used data warehousing or mining technologies, 61% document management systems, 49% decision support, 43% groupware and 38% extranets.

However, while organizations were most advanced in the use of technology to achieve KM, they were failing to exploit its full potential. Only 16% of the respondents whose companies had implemented relevant technologies said that they had a system specifically configured for KM.

In the world of academia KM has also gone through something of a hype cycle. In the mid 1990'es KM and related issues were growing fields of research. Various scholars understand and define very different things which they collect under the umbrella term of "knowledge management". For example, artificial intelligence (AI) techniques for knowledge management are based on AI methods and techniques which originated in research carried out decades ago. Generic knowledge management tools have little power beyond traditional information management, decision support systems, data warehousing or groupware systems (Ruggles, 1997).

There are other views on knowledge management which start from economic and social perspectives. Such a diversity of discourses on KM has led to a division of KM research in several schools. Earl (2001) identified three major categories: technocratic, commercial and behavioural schools in KM.

The *technocratic* schools are based on using IT to support knowledge workers in their daily activities. The systems school is based on the premise that it is possible to capture specialist knowledge and to codify it. The aim of a KM effort in this case is to create a knowledge base or a knowledge directory for an organization. A knowledge base makes it possible to reuse previously developed knowledge. It is also believed that knowledge can be transferred through the knowledge base. Creating a knowledge directory (also known as a knowledge map) pursues the goal of explication and articulation of the knowledge an organization possesses. This school allows for taking advantage of the fast growth of IT capabilities. The flaw of the approach is that it implies that knowledge is static and hence discards the possibility of embedding knowledge which is gained through practice.

The *commercial* school in KM views knowledge from the economical perspective, i.e. knowledge is studied as an asset. In the literature this approach has attracted attention when evaluating the knowledge capital of an organization (Strassman, 1999), and it offers a framework for studies of knowledge assets as part of the broader concept of intellectual capital (Edvinsson and Malone, 1997). The contribution of IT in this school of thought is to serve as a support environment which can be used to register and process information about knowledge assets.

The behavioural schools focus on knowledge exchange through social networks. The key success factors in this school reside in a sociable culture and the productivity from using knowledge can stem from providing access to knowledge within a network of motivated people. IT can contribute to effective knowledge management through groupware and knowledge representation tools (Earl, 2001).

Davenport et al (1997) made an attempt to focus on knowledge management projects in an effort to avoid abstract discussions and instead provide practically useful guidelines. To do that they have analyzed 31 knowledge management projects in 24 companies and managed to identify the key success factors. Among the most important factors they found were a good technical and organizational infrastructure, knowledge-friendly culture, long-term and effective motivational practices and senior management support.

Note 6.1. *The material of this Section has been collected by Vladimir Kvassov and Kari Leppänen of IAMSR, Åbo Akademi University, Åbo, Finland, as a part of the* Intelligent Systems in Mechanical and Base Metal Industry *(Metal IT) research project financed by Tekes under contract No. 131/02.*

3. Knowledge Management: A Conceptual Framework

Knowledge management is viewed from diverse perspectives, using different vocabularies and terminology. Thus we need to give a definition of knowledge and knowledge management as there are no commonly accepted definitions. There are several quite often applied definitions, which usually stem from the notion of knowledge as an object. The most often cited definition is the one given by Davenport and Prusak (1998):

> "knowledge is a mix of framed experiences, values, contextual information and expert insights that provides a framework for evaluating and incorporating new experiences and information"

Knowledge is thought to be of two types, explicit and tacit (Polanyi, 1967; Nonaka & Takeuchi, 1995). Explicit knowledge is that knowledge, which can be codified and stored in computer-based systems. Tacit knowledge is thought to be in people's heads and is very difficult to codify and store.

Knowledge can also be defined in terms of the function it serves (Zack, 1999). That is, knowledge may be "declarative" or descriptive in describing *what* something is. Knowledge may also be "procedural" or process-oriented in describing *how* something is done. Finally, knowledge may also be "causal" describing *why* something happens. Knowledge can also be described in terms of its specificity. That is, some knowledge is of a general nature that can be used as background or context for many situations. Other knowledge is more specific and applicable to only a very narrow context. The concept of knowledge is typically approached through the 'data-information-knowledge' chain as it shown in Fig. 6.1. Data are observations, facts or images. Formalized, filtered, contextualized and summarized data constitute information.

Finally, information which is enriched by ideas, rules and procedures that allow actions and decision-making constitute knowledge (Leibowitz, 1999). From the organizational perspective knowledge is viewed as processed information embedded in routines, processes, products, rules and culture that enable actions (Beckman, 1999). The building blocks of knowledge can be represented in the form of a pyramid as shown in Fig. 6.1 (l'Association Européenne pour l'Administration de la Recherche Industrielle, 1999).

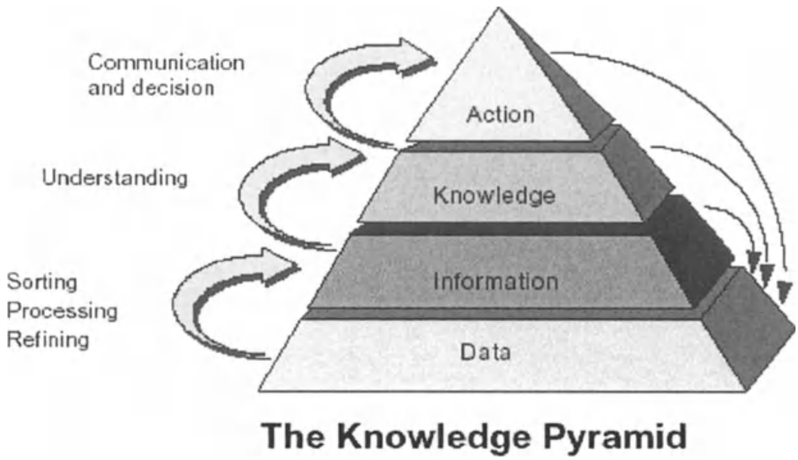


Figure 6.1. The Knowledge pyramid (l'Association Européenne pour l'Administration de la Recherche Industrielle, 1999).

Intuitively people understand that knowledge is something broader and deeper than just information. The definition of knowledge presented through the pyramid is not to deliver an epistemological basis (i.e. to answer the question "what does it mean to know something?") but rather to underline that knowledge is far from simple. Knowledge can come in a variety of types and formats, and serve a variety of purposes. It is considered an extension of information in that knowledge is "embedded" within a context and gets ideas, rules and procedures from that. This makes it more challenging to manipulate and manage in a systematic way than just information.

Next we will discuss in greater detail the concepts of knowledge as an object, an interpretation, a process and a relationship.

Knowledge as an object

The fundamental idea of this view is that knowledge can be represented by means of using aggregation and symbolized representations. Knowledge is seen as transferable and is perceived as an entity that can be transferred accurately between human brains.

The general assumptions about knowledge are as follows:

- knowledge is a representation of given world
- human intelligence is seen as information processing and rule-based manipulation of symbols
- knowledge is objectified and transferable, and
- learning is seen as creation of the most accurate representation of reality

This view has its roots in cognitive science that views human intelligence from a mechanistic perspective. The intelligence is seen as a result of performing information processing that can be drastically improved by computation. This view, which is closely related to Herbert Simon's paradigm of information processing, has long dominated the management field. According to this view, organizations can be described as machines that continuously process information and data for rational purposes (Simon, 1981). The view of knowledge as an object contributes to a better understanding of explicit knowledge and makes it possible to utilize the growing capabilities of computer-based systems. They are efficient for capturing knowledge that is static and unchanging over time. Based on this view an organization, which undertakes KM efforts should adjust their strategies to focus on its information processing capabilities.

This view has been criticized in the recent years (e.g. Winograd and Flores, 1986; Weick, 1995). The major problem in the idea of representation is that there exists knowledge that cannot be codified, transmitted or processed in a mechanistic fashion. There is always a tacit dimension of knowledge that cannot be adequately perceived when detached from a human or decomposed into its parts.

The object representation of knowledge is easily carried out with fuzzy sets and the information processing is supported with fuzzy logic.

Knowledge as an interpretation

The major assumption for this concept is that knowledge intrinsically associated with human subjective judgments and is defined by the context. The fundamental difference from the previous view is that it views knowledge as a socially created construct rather than an objective representation.

This view addresses knowledge as "... the result of mutual interpretive action and linguistic behaviour, which depends on the entire previous experience" (Winograd and Flores, 1986). Both knowledge understood as an interpretation and as an object treat knowledge as a static construct. Needless to say, knowledge as an interpretation and defined by its context represents a challenge for systematic research. Some recent developments in computation with words and perceptions (as introduced by Lotfi Zadeh in several keynote addresses in 2002-2003) may offer a conceptual framework for advances in interpretation-based knowledge research.

Knowledge as a process

Using a cause-effect analysis in attempt of understanding complex problems may be an oversimplification, even if this is the rational approach we are trained to use. Nonaka and Takeuchi (1995) advocate the building of a *knowledge-creating company*, arguing that knowledge should be viewed as "a dynamic human process of justifying personal belief toward the *truth*". From a process-oriented view, knowledge is not a static entity but the manifestation of a dynamic process of *knowing* by which human beings make sense of the world and reality (Varela et. al, 1991) in (Kakihara & Sorensen, 2001).

KM from a process perspective can be exemplified by such techniques as business process re-engineering (BPR). It has been found exceedingly difficult to come up with a theoretical framework that would take into account the dynamic factors of organizational processes. The high failure rate of BPR projects underlines how problematic it is to capture and understand the dynamics of organizational knowledge and to carry out a practical implementation of a KM initiative.

Knowledge as a relationship

Some recent research in the KM field has pointed at the importance of taking into account the emergent nature of knowledge processes. Emergent knowledge processes are organizational activity patterns that are characterized by three major factors: deliberation without one best structure or sequence; uncertainty and unawareness of the actor prior knowledge, and a variety of information requirements that include both general and specific knowledge (Markus et al., 2002).

The process and relationship oriented views of knowledge is the domain of information systems and support technologies, which we will work on later in this chapter.

Knowledge is not isolated but framed by contextual factors. Unlike data or information knowledge emerges from subjective human interpretations and complex interpretations between human beings (Nona & Takeuchi, 1995). We advocate using the definition of knowledge as *a network of relations through which humans coordinate their actions* (Zeleny, 1987). On one hand this definition brings out tacit dimensions of knowledge. On the other hand it makes it possible to understand and use information technology as part of a relationship rather than as a tool for mechanistic information processing.

4. Knowledge Management Strategies

There are two principally different approaches to managing knowledge: codification and personalization (Hansen et al., 1999). In some companies, the strategy is focused on information technology and the building of information systems. Codification drives processes through which knowledge is carefully codified and stored in databases, where it can be accessed and used by anyone in the company. In other companies, knowledge is closely tied to the person who developed it and is shared mainly through person-to-person contacts. The purpose of information systems in such companies is to help people communicate knowledge, not to store it.

The choice of strategy is conditioned by the economics of company processes, the people it hires and the way the company serves its clients. The original work conducted by Hansen et al focused on consulting companies. In fact, consulting companies are among the earliest adopters and users of the KM concept as knowledge is their core asset. However, it was also found that the codification and personalization strategies for managing knowledge are not used only in consulting. An analysis of IT companies and health care providers demonstrated the same two strategies at work (Hansen et al. 1999)

Codification strategy

The codification strategy is often used by large companies, which have technology as their key driver. For example Accenture and Ernst & Young, have pursued a codification strategy. Over the recent years they have developed elaborate ways to codify, store, and reuse knowledge.

Knowledge is codified using a "people-to-documents" approach: it is extracted from the person who developed it, made independent of that person, and reused for various purposes.

As an example, Accenture has created a knowledge space where the employees share their best practice cases for specific industry problems and processes. The knowledge gained during performing assignments codified and stored in the knowledge base. Every consultant is supposed to contribute to the knowledge base regularly. Such an approach makes it possible to get access to a globally generated and codified expertise across the company.

Personalization strategy

In contrast to the codification strategy other firms, such as Boston Consulting Group and McKinsey, emphasize a personalization strategy. They focus on a dialogue between individuals, not on knowledge objects in a database. Knowledge that has not been codified and probably couldn't be transferred in brainstorming sessions and one-on-one conversations. Human actors collectively arrive at deeper insights by going back and forth on problems they need to solve. The companies that pursue a personalization strategy typically develop electronic document systems, but the purpose of the systems is not to provide knowledge objects but to give the user references to similar work that has been done by someone else in the company, so that the user could approach that person directly. A comparison of codification vs. personalization strategies is presented in Table 6.1-6.2-6.3. (Hansen et al, 1999)

The selection of the right strategy depends on the context and the product/service provided. If a company provides a standard product that does not change much, then there is a high probability that much of the organizational knowledge can be explicated and reused. In contrast, a company that delivers products/services with a high degree of customization can make very limited use of codified knowledge. Thus they would benefit more from following a personalization strategy. Another issue to consider in the strategy selection is the maturity of the product. It is reasonable to expect that operations to create a mature product are well structured and, thus well understood. However if a company pursues the creation of an innovative product then it can hardly reuse previous knowledge which has been documented. The critical factor in working on a KM strategy is to make a decision to pursue a particular strategy. The codification strategy is supported with fuzzy database construction and application methods, the personalization strategy with intelligent support methods (such as approximate reasoning) for communication, joint development work and problem solving.

Table 6.1. Comparison of KM strategies.

COMPETITIVE STRATEGY	
CODIFICATION	PERSONALIZATION
Provide high-quality, reliable and fast information-systems implementation by reusing codified knowledge.	Provide creative, analytically rigorous advice on high-level strategic problems by channelling individual expertise.
ECONOMIC MODEL	
REUSE ECONOMICS	EXPERT ECONOMICS
Invest once in a knowledge asset, reuse it many ti Focus on generating large overall revenues.	Charge high fees for highly customized solutions to unique problems. Focus on maintaining high profit margins.

5. Knowledge Management Projects

Information technology was developed to process and work with information, not knowledge, and as a consequence it may try to change knowledge into information-like objects. When it succeeds we will have a problem as Tiwana notes: "Information does not necessarily translate into knowledge, for much knowledge is too tacit and too obliviously ingrained in people's heads to be codified – let alone transferred electronically." Andrew Michuda, the chief executive of Sopheon, which provides knowledge management software and manages a network of thousands of technical experts and analysts makes a similar point and describes how knowledge management goes wrong: "KM hits a wall when it is generically applied. You need the richness of human interaction with the efficiencies of technology, focused on a knowledge- intensive business application. Knowledge management is much more effective if it is not a stand-alone button on somebody's PC but is integrated into a key business process."

Davenport and Prusak (1998) identified four main types of KM projects:

- Building knowledge repository

  o Determining the technology for storing knowledge

  o Persuading employees to contribute to repository

Table 6.2. Knowledge management strategy.

KNOWLEDGE MANAGEMENT STRATEGY	
PEOPLE-TO-DOCUMENTS	PERSON-TO-PERSON
Develop an electronic document system that codifies, stores, disseminates, and allows reuse of knowledge	Develop networks for linking people so that tacit knowledge can be shared.
INFORMATION TECHNOLOGY	
Invest heavily in IT The goal is to connect people with reusable codified knowledge.	Invest moderately in IT The goal is to facilitate conversations and the exchange of tacit knowledge.
HUMAN RESOURCES	
Hire new college graduates who are well suited to the reuse of knowledge and the implementation of solutions. Train people in groups and through computer-based distance learning. Reward people for using and contributing to document databases.	Hire MBA's who like problem solving and can tolerate ambiguity Train people through one-on-one mentoring. Reward people for directly sharing knowledge.

o Creating a structure for holding a knowledge

- Knowledge transfer: to identify and monitor human and electronic channels for knowledge sharing
- Knowledge asset management

  o Calculating knowledge valuations

  o Negotiating with holders of desired intellectual capital

  o Managing a knowledge asset portfolio
- Infrastructure development

  o Analyzing financial needs

Table 6.3. Examples.

PEOPLE-TO-DOCUMENTS	PERSON-TO-PERSON
Andersen Consulting	McKinsey & Company
Ernst & Young	Bain & Company
Dell	Hewlett-Packard
Access Health	Sloan-Kettering Cancer Center in New-York

o Projects with external vendors of technologies and services

o Human resources development

The line drawn between different project types is mainly for discussion purposes as the four types of projects complement each other. A stand alone project to create a knowledge repository is not feasible as such, but an effective knowledge transfer process can be built and implemented by constructing a knowledge repository. Such a project would inevitably require changes in the technological and organizational infrastructures.

All four KM project types benefit from the use of fuzzy modelling and methods based on fuzzy logic.

5.1 Knowledge Repositories

Knowledge repositories are meant for storing knowledge. Most of the KM projects include some kind of a knowledge repository (Davenport and Grover 2001). The repositories typically contain a specific type of knowledge for a particular business function or process. According to Davenport and Grover (2001) they can be used for:

- Best practices knowledge within a quality or business process management function
- Knowledge for sales purposes involving products, markets, and customers
- Lessons learned in projects or product development efforts
- Knowledge around implementation of information systems
- Competitive intelligence for strategy and planning functions

- "Learning histories" or records of experience with a new corporate direction or approach

There are a number of software systems used for knowledge repositories such as Lotus Notes, Web-based Intranets and Microsoft Exchange.

In the case of structured, explicit knowledge the knowledge is often in form of a document. Tacit knowledge can be stored e.g. in the form of discussions or other free- format. Davenport & Prusak (1998) categorize the use of knowledge repositories into three different categories:

- *External knowledge* means knowledge that is captured outside the company. For example, competitive intelligence falls into this category.
- *Structured internal knowledge* means documents such as research reports, product-oriented marketing materials or different techniques and methods. This kind of information is easy to categorize under clear categories and the source of the in- formation is internal to the company.
- *Informal internal knowledge* is gained during the operations of the company and it cannot be easily categorized. Examples of this kind of information are "lessons learned"-type of material collected during some specific project or assignment. The repositories are often built on informal internal knowledge with the help of intelligent tools, such as (for instance) the Autonomy knowledge management software system[2]. Their mission is to provide a software infrastructure that automates operations on semi-structured and unstructured information in any digital domain. In practice they offer a highly advanced search tool, which help users to find information and experts from unstructured internal knowledge.

The first two kinds of knowledge can be supported with the software agent technology we will discuss later on in this chapter.

One possibility to classify the repositories is to make a distinction between repositories which are meant for storing documents and repositories which are meant for storing data (Markus, 2001). Companies often attempt to transform raw data into usable knowledge as a part of their knowledge management initiatives. These projects typically involve isolating data in a separate data warehouse for easier access. Statistical analysis and data mining tools are then used to translate the data into knowledge. Because of that they are increasingly addressed as a part

[2]www.autonomy.com

of knowledge management (Davenport & Grover 2001); this kind of activity if often referred to as *Business Intelligence.* For example Gartner group defines business intelligence as "a user-centred process of exploring data, data relationships and trends, thereby helping to improve overall decision making. This involves an interactive process of accessing data (ideally stored in a data warehouse) and analyzing it to draw conclusions, derive insights and communicate findings with the purpose of effecting positive change within an enterprise."

Dubois et al (1992) works out some principles for handling defect material in knowledge bases with the help of fuzzy logic. There are in principle two types of defects we may encounter: the material may be incomplete or inconsistent - in the first case there is missing knowledge, in the second case there may be a local excess of knowledge. As we want to use the knowledge for reasoning (i.e. make conclusions and establish new knowledge) and we have incomplete or partial knowledge the truth of the propositions we make may be partly or fully questionable, or even unknown. If we start with inconsistent knowledge - which is due either to errors or to new, added knowledge which contradicts existing knowledge - we have the same problem, the truth of a proposition cannot be determined and the reasoning process remains incomplete as in classical logic anything can be deduced from inconsistent knowledge. Inconsistent knowledge can be dealt with in the framework of possibilistic logic as there exists an ordering among the knowledge elements, which is constructed from a certainty grad- ing among the elements.

The Dubois et al framework illustrates that there is an emerging body of theory for handling knowledge depositories with a fuzzy logic framework, which should be further explored and developed.

5.2 Knowledge Transfer

Knowledge transfer means transferring specific knowledge about an issue from one employee to another or to a group of people or throughout the organization. One common way to structure knowledge is to divide it in explicit or tacit. Nonaka (1995) identifies four possible modes of how knowledge can be transferred: socialization, externalization, internalization and combination:

- *Socialization* means sharing tacit knowledge between individuals, usually through joint activities rather than through written instructions. Mentoring is an example of this kind of activity.

- *Externalization* is the process of expressing tacit knowledge in an explicit and understandable form. An example of this is the conventional teaching and learning methodology which requires that the professor's knowledge is externalized as an initial step in the student's learning process.

- *Internalization* is conversion of explicit knowledge to an organization's tacit knowledge. This can be done e.g. through learning-by-doing, on-the-job training, learning by observation and face-to-face meetings.
- *Combination* involves the conversion of explicit knowledge into more complex sets of explicit knowledge. This happens through focusing on communication, diffusion, integration, and systematization of knowledge and by creating new knowledge through these activities.

There is no reason to look down on the various forms of informal conversation which takes place as part of normal social activities in an organization. In fact, during those conversations work issues are also covered and therefore these informal discussions help to spread knowledge inside the company. Some Japanese companies have developed this concept further by having so called "talk rooms", where every employee is expected to spend 10-20 minutes a day. The idea is that people visit these rooms and talk about their work to each other in an unstructured way.

Another way for companies to share knowledge is to have special "knowledge fairs" where employees present what knowledge they have. The idea is that employees could pretty freely wander around and talk about different issues which they are interested in.

One way to share information on who knows what is to create knowledge maps. The idea of these maps is to share the information about the specific knowledge areas of different people. These "yellow pages" of corporate knowledge guides people looking for specific information to the person who knows about it.

The employees need some motivation for sharing information. Different people have different reasons to share information (Davenport & Prusak (1998)):

- Reciprocity
- Reputation
- Altruism

Reciprocity means simply that "if I help you, you will help me". Employees know that if they give help to others, they will in return receive it when they need it. *Reputation* affects the willingness to share information. A person sharing information usually wants others to recognize him as a person who has valuable expertise which will help and benefit his co-workers. A third motivation to share information can simply be based on *altruism*. "Thank you" is enough for some people and they do not even want to get bigger favours in return. Mentoring can be seen as a form of knowledge sharing which is based on altruism.

There are several things which have to be taken into consideration when working with KM transfer projects:

- *Same language*: users who share the knowledge must use the same language. This is self-evident, but there are examples from the past where this point has been neglected and no results have been gained because of this.

- *Status of the knower*: the status of the knower affects people who get the knowledge from him. The higher the status the better the information is expected to be - this might be true in some cases, but it should not be accepted as a general rule of thumb.

- *Access to the information*: access to the information does not guarantee that people will use it. People have to be motivated to use it and to contribute to common knowledge.

5.3 Knowledge Asset Management

In contemporary economy the intangible "soft" factors of productivity (e.g. quality, timeliness) are at least as important as the tangible "hard" factors (e.g. output of a production unit) (cf. Brynjolfsson, 1998; Chan, 2000). The productivity of a company depends on the knowledge residing in the organization. The increasing role of intangible assets, such as knowledge and intellectual property, urges organizations to re-consider the evaluation of assets, processes and practices based only on financial values.

In recent years, there have been calls for finding adequate metrics of corporate knowledge assets, because as with any other scarce resource corporate knowledge needs to be managed productively.

A knowledge asset is a "...combination of context sensing, personal memory and cognitive processes" (Skyrme and Amidon, 1997). Measuring a knowledge asset requires that we evaluate people's individual and collective capabilities and the intelligence of an organizational information system. Another definition of a knowledge asset is that it is a created "...when the know-how or experience of individuals can be used by someone other than those involved in its creation" (Baird & Henderson 2001).

To incorporate the measuring of knowledge assets into existing practices is a challenging task that requires introducing new concepts, definitions, criteria and the operationalisation of concepts. The term "knowledge assets" belongs to the wider domain known as "intellectual capital" - this is defined as "possession of knowledge, applied experience, organizational technology, customer relationships and professional skills that provide a competitive edge in the market" (Edvisson and Malone, 1997). Using this distinction, there are a number of models which have been developed to measure and manage knowledge assets.

Skandia was probably one of the first large companies that made a consistent effort at measuring knowledge assets. The model that was created is called Navigator and has five areas of focus: financial, customer, process, development and human capital (Evidsson and Malone, 1997). *Human capital* is defined as the combined knowledge, skill, innovativeness and ability of the company's individual employees to meet the task at hand. It cannot be owned by a company.

Structural capital is the hardware, software, databases, organizational structure, patents, trademarks and everything else of organizational capability that supports those employees' productivity. Unlike

Human capital it can be owned and traded. *Intellectual capital* is the sum of structural and human capital. Skandia used this approach to combine financial and non-financial reporting, to visualize its intellectual capital and to connect organizational activities with the strategic goals of the company. The model uses up to 91 metrics related to intellectual capital and 73 traditional metrics. The inventors of the model admit that some of the metrics vary in importance and may even be redundant, but still recommend 112 metrics.

The Navigator dimensions have 36 monetary metrics cross-referencing each other. The approach presented in the Navigator model is similar to the framework of Balanced Scorecards (BSC) originally presented by Kaplan and Norton (1996).

The *Technology Broker* model was proposed by Brooking (1996). He suggests that knowledge assets should be worked out as a mixture of the following elements:

- Market assets (brands, customer, repeat business, backlog, distribution channels, contracts and agreements such as licensing and franchises)

- Human-centred *assets* (the collective expertise, creative and problem-solving capability, leadership, entrepreneurial and managerial skills embodied by employees of the organization

- Intellectual property *assets* contain the legal mechanism for protecting many corporate assets and infrastructure assets including know-how, trade secrets, copyright, patent and various design rights, trade and service marks

- Infrastructure *assets* (technologies, methodologies and processes, corporate culture, methodologies for assessing risk, methods of managing a sales force, financial structure, databases of information on the market or customers and communication systems

The approach, which is very explicit and straightforward, is made operational through a set of questions presented in a questionnaire.

The *Economic Value Added* model argues that the emphasis in IT productivity should be shifted from assessing capital-asset ratios to assessing the assets related to the knowledge capital of an organization, for which it is suggested to use economic-value added (EVA). The use of EVA (profits after taxes minus payments for shareholder capital) makes it possible to link knowledge management to productivity, and to calculate the productivity in monetary terms (Strassmann, 1999b).

There is broad consensus that a sustainable competitive advantage can be achieved through investments in knowledge assets. The problem of such investments is that they are difficult to evaluate and judge with existing investment tools such as discounted cash flow (DCF).

The problems with DCF fuelled the interest and quite some excitement around the application of real options for strategic investments. Based on an analogy with financial investments, the logic of real options is that an organization can make a small investment that provides an opportunity but not a commitment to pursue a full scale investment later. Knowledge-based options differ from financial options in two different ways (Coff & Laverty, 2001):

- significant uncertainty remains at the exercise decision

- the value of knowledge depends on its transfer and integration within the firm

Unlike physical financial assets, knowledge can be transferred throughout the organization and applied to various projects and processes. Real options on knowledge assets is not limited by any specific option pricing model, they can be built both from formal models and from heuristics.

Real options can be valued using the analogue option theories that have been developed for financial options, which give us a method for assessing the value of investments which is quite different from traditional DCF approaches. With the traditional models investment activities or projects are often seen as now or never, and the main question is whether to go ahead with an investment or not. Decisions are hard to make as the context is uncertain and the outcome is uncertain - this is of course even more true for investments in knowledge assets as the actual value of these assets is hard to estimate. Traditional DCF methods ignore the value of flexibility and discount heavily for external uncertainty involved, and as a consequence many interesting and innovative activities and projects are cancelled because of the uncertainties. The real options theory offers a remedy for this, the real options valuation methods make explicit use of flexibility and finds a value for flexible solutions.

Investments should be treated flexibly as in real life it quite often is possible to delay, modify or split up a project in strategic components, which generate important learning effects (and therefore reduce uncertainty). The new decision rule which is derived from the option pricing theory is that an investment should be made today only if the net present value is high enough to compensate for giving up the value of the option to wait. The option to invest loses its value when the investment is irreversibly made and this loss is an opportunity cost of investing.

It turns out that real option valuation can be done in a more useful way with fuzzy numbers (see Chapter 4).

It appears to be a reasonable proposal that investments in knowledge assets could be handled with the fuzzy real option valuation methods.

The value of knowledge grows as more people get access to it. Thus the real options on knowledge assets should be viewed from the perspective of accessibility and integration of the project in the existing infrastructure of an organization. There are dilemmas with the uncertainty at the time to exercise a decision and the integration/isolation of knowledge assets with other resources. The risk of a higher commitment to a failing project grows with the degree of integration. The risk can be minimized by isolating the project, which then - on the other hand - may diminish the potential advantages of a good project.

There are many cases in industry - and more specifically in research and development of technologies - when an initial integration or isolation of the option has led to inefficient knowledge asset management. For example the Palo Alto Research Centre, which was an isolated subunit of XEROX, was not able to take full advantage of its innovations, such as the PC, local area networks and the mouse interface. The research unit created unique expertise that was incompatible with routines, culture or technology.

Another example is the RSA Corporation which developed a unique expertise in LCD technology in the 1970s and later terminated the research program. From a conventional perspective that was a completely justified decision, but it led to losing a competitive advantage in LCD technology that has been subsequently developed in note-books, hand-held computers etc.

R&D programs often create capabilities that support future opportunities to expand. Real options on knowledge assets make it possible to implement a stepwise approach to an investment. Such an approach reduces the risk of making one single large investment.

Technology *per se* cannot turn an organization into a knowledge-creating company. However, organizations still often see KM as a purely technological solution. According to the Knowledge Management Research report (KPMG 2000), organizations adopted a set of technologies (internet/intranet, data warehousing and decision support systems) but only 16% of the studied 432 companies implemented relevant technologies specifically configured for KM.

The problems encountered during KM projects mostly concentrated around information overload (69%), lack of time in sharing the knowledge (62%) and not using technology to share knowledge effectively (65%). On the other hand, companies which have undertaken KM projects have demonstrated a remarkably higher speed of access to information. For example, 60% of the companies with a KM program could figure out whether the research have been carried out by another business unit or competitor in half a day versus 43% of those companies without a KM program. Respondents were also asked about their expectations from KM. Better decision- making and faster response to key business issues were among top scorers (86% and 83% respectively).

6. Research in Knowledge Management - Some Methodology Issues

Knowledge management is an artificial construct (even if the costs incurred in KM projects are real enough) and it is often found to be difficult to introduce a concept in an organizational context and to make it work as (i) nobody really understands the concept, (ii) nobody knows how to implement it and (iii) the consequences of actually making it work are not very clear.

In a 2-year research program[3] with three major multinational corporations representing the forest products, the mechanical and the base metal industries we worked out some principles for constructing, building

[3]The *Intelligent Systems in Mechanical and Base Metal Industry* project has been financed by Tekes under contract No. 131/02.

and implementing KM tools in the organizations. Here we will simply summarize sum lessons learned in the process:

- KM can be handled with web-based, practical, simple, inexpensive applications for improving everyday activities
- KM is an evolutionary process: start simple, then work in more advanced, demanding applications
- KM is people's business: people have and need knowledge, people will have to share and use knowledge; management should "walk the talk"
- Robust KM systems can be built and implemented with standard software
- KM should be problem-driven rather than technology-driven; technology cannot deliver KM
- KM technology is an enabler; should address the daily needs of its potential users
- KM technology should be used to connect people to data, information and knowledge - and to other people (much knowledge is tacit)
- KM tools should be built on existing information and communication architectures, i.e. the existing infrastructure
- KM and its support technology should be embedded in work processes with the users in control of the tools and the applications
- Knowledge will become obsolete, irrelevant or wrong - KM depositories should be maintained
- There are limits to knowledge sharing due to confidentiality, privacy, etc. - KM technology should support these limitations
- There should be different channels for knowledge transfer for different contexts and users

Various research approaches were tested in the process and it became quite clear that non-traditional methods could offer most insight. Knowledge as such is emergent and dynamic and knowledge management should be flexible and adaptive to changes of the knowledge substance. Knowledge management projects are to a significant extent influenced by the context in which they are carried out, which makes it difficult to apply any kind of generic framework to them.

The approach we used and which is much supported in the literature is actions research. Actions research is one of the preferred research methods in the study of organizations, managerial activities and also the building and implementation of information systems (Iivari et al., 1998). The assumptions of action research focus on the collaboration and interaction between researchers and practitioners (Baskerville and Wood Harper, 1996, Lau, 1997; Avison et al., 1999) in an organizational intervention that aims at organizational change. The researcher is intended to bring an intellectual and theory-based framework into the context while the practitioner brings (tacit and explicit) knowledge of the context, experience and practical insight (McKay and Marshal, 2001). When this interaction and collaboration is carried out properly we will have both a sound basis in theory and a genuine insight in practice, which appear to be wanted features in any research program in KM.

Action research has the following properties (Bargal, et al, 1992):

- a cyclic process of planning, action, and evaluation;
- continuous feedback of the research results to all parties involved;
- co-operation between researchers, practitioners, and clients from the start and throughout the entire process;
- application of the principles that govern social life and group decision making;
- taking into account differences in value systems and power structures of all the parties involved in the research;
- using action research concurrently to solve a problem and to generate new knowledge

One of the benefits with actions research is that it allows researchers to study the interplay between humans, technology and a socio-cultural context, actions research helps to capture the real world in a greater detail (Baskerville and Wood-Harper, 1996). The major critique of actions research as a methodology is focused on the subjective bias of the researchers and the difficulties to generalize results. In actions research the researchers are actively involved in the research process and in the organizational change being studied. A consequence of this is that the validity of cause-effect relationships, which have been found and explained, can be questioned - it may not be clear what phenomena or events were studied, what were the organizational activities and how the influence of the researcher interacted with both sets of factors. Actions research is also highly situational which makes it difficult to draw conclusions and make generalization for similar problem situations in a different context - the ongoing debate if we can generalize from a limited set of case studies.

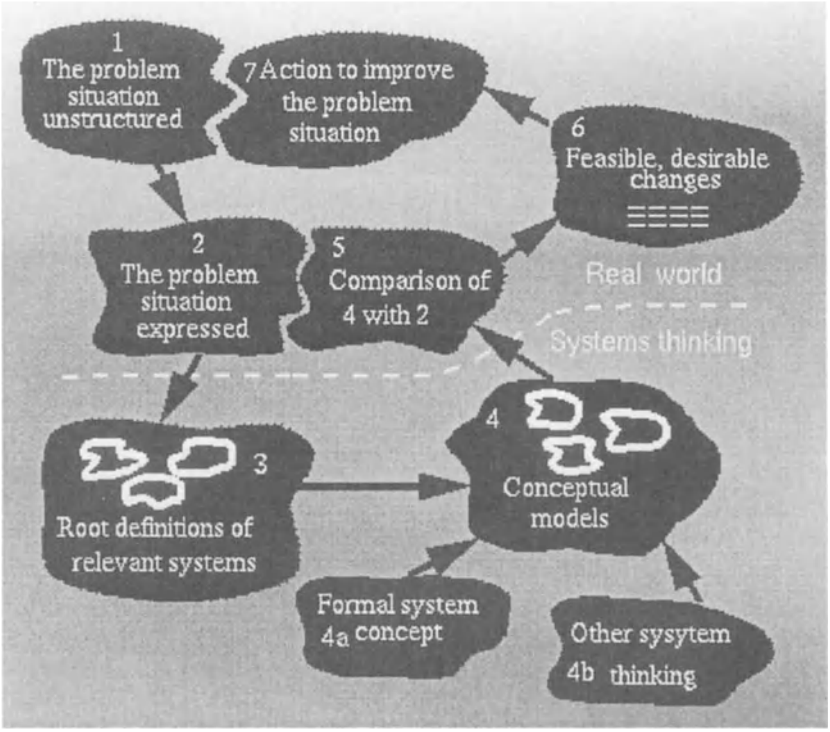


Figure 6.2. Soft Systems Methodology (after Checkland, 1981).

Another approach with quite some promise for systematic work with knowledge management is the soft systems methodology (SSM), which was developed and extensively tested in a number of practical cases of three decades. The central idea of SSM is to use the "human activity system" model to conceptualize a system that "serves helps and supports people taking actions in the real world" (Checkland and Holwell, 1998). Quite often the SSM combines with actions research to get a better understanding of the human issues involved - we used this approach in our own research project.

The SSM studies processes within organizations as a human activity system which is built from operational sub-systems, which in turn includes a set of interdependent activities which form a purposeful whole. There is an overall monitoring and control sub-system that is responsible for measuring performance and carrying out adjustments of the system in order for it to survive (Checkland and Holwell, 1998). The SSM has been shown to provide quite functional models of reality, which help to make key questions about problems and contexts explicit and, therefore, will help reveal the logic underlying organizational processes.

SSM is an approach that presumes a learning process through the following stages (cf. Fig. 6.2):

- The exploration of a perceived problem situation,
- The selection of relevant systems of purposeful activity, which
- Enables a structured exploration of the problem situation, and
- Yields knowledge, which is relevant to improving the problem situation, which leads to,
- Actions to improve the problem situation

SSM allows us to follow up and study constantly changing social processes and to tackle ill-structured problems, elements which are prevalent in most KM projects and studies.

7. IT-Solutions to Support Knowledge Management

Making knowledge accessible across the organization is often sought by KM projects. In fact, the reuse of past experiences and lessons learned can reduce the effort in carrying out a similar project, hence improving productivity. Knowledge is classified as either tacit (embedded in the human mind) or explicit if it can be easily codified (Nonaka and Takeuchi, 1995). In an organizational setting the value of knowledge grows as it becomes accessible and explicit, which can be accomplished through the use of information and communication technologies and some proper modelling instruments. We will work this out in the following sections.

PriceWaterhouseCoopers - one of the pioneers in the integration of KM into business strategy - suggests a way to map technologies according to how they can be used to manage knowledge across companies (cf. Fig. 6.3).

The PWC taxonomy is generic and general, and it is focused on showing classes of tools which may be useful for distributing knowledge throughout the organization.

Here we will use another approach, we will go more into details and work on some of the problems which are prevalent in knowledge management and can be dealt with if we apply some innovations from modern information and communication technology.

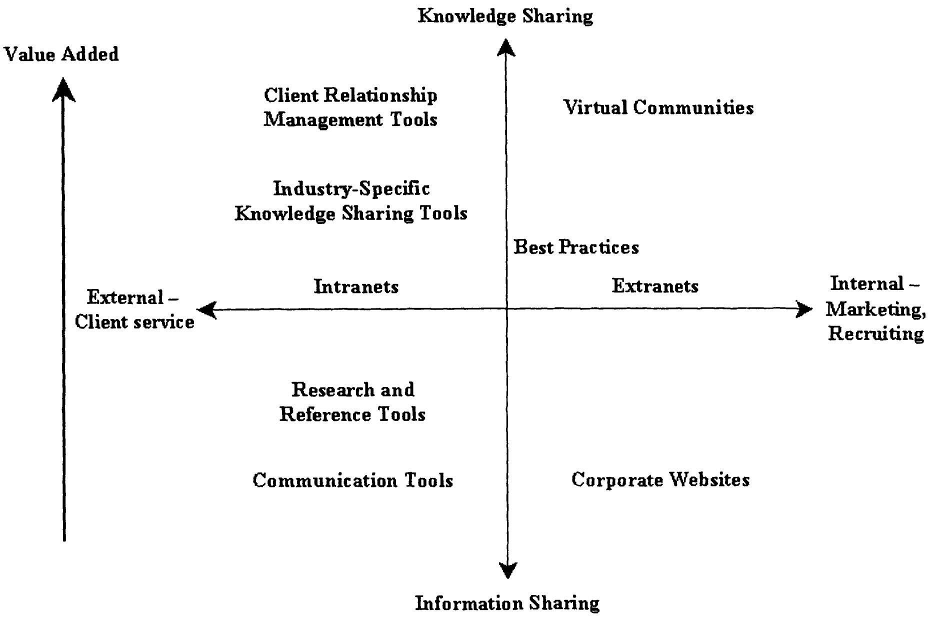


Figure 6.3. Mapping technologies for KM (Kelleher, PriceWaterhouseCoopers, 2002).

For the time being we will assume that we have collected data, information and knowledge in a data warehouse and we want to make this accessible for multiple users in an organization. Besides the data warehouse (DW) we have a software agent (SwA, which actually is built as a multi-agent system) to operate with on the DW material.

Let us start with the most unstructured part first, the making sense of data collected in a data warehouse. Thus, we want the SwA to:

Help and support when making sense of large amounts of data. This involves a number of functions:

1.1 Periodically visiting the data warehouse, watching for new or recent data, tracking updates of key issue indicators and triggering signals to show significant changes.

1.2 Comparing and relating new data to existing data set, recognizing and selecting significant events, trends, and deviating signals.

1.3 Support the user in reasoning and explaining about the possible causes for the events and trends.

1.4 Support the user in identifying the major groups of issues and in assessing their impacts, in predicting the probability of occurrence and in formulating the development course and milestones.

1.5 Ranking the issues according to the perceived impacts and probability of occurrence and development. The ranking may be interactive and supportive of the user.

1.6 Generating summary reports of the results.

The objectives here are (i) to save time for the user, and (ii) to quickly focus work with the data on meaningful subsets of data. Let us then move to more specialized support functionalities.

Help and support in identifying results worth further attention. This again involves a number of functions:

2.1 Specified input/output data to and from planning (or problem solving, decision) models is evaluated in relation to reference points or benchmarks, and is classified as *normal* or *unusual*; the latter category is singled out for further attention.

2.2 Specified input/output data used and worked out in planning scenarios is evaluated as *plausible* or *unplausible* with the help of reference points or benchmarks; the latter category is singled out for more work and data collection.

2.3 Selected (but not necessarily specified) input/output data used and worked out in open world (OW) scenarios is evaluated in terms of plausible or implausible, and in terms of the categories (*crisis, opportunities* and *threats*) with the help of reference points and benchmarks (which may be imprecise); the categories being plausible and which are found to represent *crisis, opportunities* and *threats* are singled out for more work and a continued gathering of data from selected data sources.

2.4 Collected data in the data warehouse is evaluated against keywords, benchmarks and reference points (if numerical), and against subjective assessment criteria; data singled out as *unusual* will be the focus of a continued collection of data and further study.

The objectives will now be to help the user (i) to focus his/her work on essentials, and (ii) to get a better understanding of the context, which may not be possible without the support of the SwA.

Now we can take one more step towards a further specified functionality.

Help and support in tracing potential cause-effect chains. This involves a number of functions; we will move from the most specific to the most open-ended:

3.1 When working with several planning (or problem solving, decision) models, the SwA should follow (and on request display) the input and output data used for and produced by the models. The patterns thus derived may indicate cause-effect relationships.

3.2 When working with planning scenarios, the SwA should follow (and on request display) the sequence and combinations of models used. The scenario patterns may show cause-effect relationships among the events built in the scenarios when displayed over time.

3.3 When working with OW scenarios, the SwA should keep trace of data variations in relation to reference points and benchmarks. When displayed over time, the scenario patterns may show underlying cause-effect relationships, or may indicate where further data gathering may reveal cause-effect relationships.

3.4 When working with sets of data in a data warehouse, cause-effect relationships are difficult to trace. If benchmarks or reference points can be established, variations in relation to these may be traced and displayed over time to suggest cause-effect relationships.

The objective here is simply to help the user trace potential cause-effect relationships, which may be important if no relationships have been known before.

Let us then take a final step towards a specified functionality.

Help and support in finding similar results. This support function will contain one part:

4.1 When working with planning (or problem solving, decision) models and finding some specific results, we may want to know if these results already have been derived with some other model or have been collected from some data source. The SwA should use the output to initiate a search for *similar* results in the data warehouse (DW) which is used as a basis for input data.

The objectives here are (i) to avoid inconsistency by having similar results analyzed and worked on in parallel, and (ii) to find similarities in time, and avoid double work.

The functionality we have described in (1.1)-(4.1) above shows how we can support four core functions of knowledge management with agent technology. The SwA is a scanning agent, which also has the necessary functionality to identify elements. Scanning and interpretation are intertwined processes, and it is tempting to extend the agent functionality to interpretation. While scanning is built for seeing and perceiving the environment, interpretation works on construction, impact analysis and the assem- bling of conceptual schemes.

The aim of scanning is to capture what is going on in the environment and to recognize only those events that are relevant to our own business, as well as to classify the chaos of data into structures. Interpretation aims to understand the identified events, to bring meaning out of observations, to discover plausible relationships and structures (e.g. cause-impact maps), and to develop frames of reference or models for understanding (Daft and Weick, 1984).

Scanning is collecting data. Interpretation is translating the data into understanding. It is a sense-making process, in which people assign meanings to ongoing occurrences (Gioia and Chittipeddi, 1991).

More specifically, if we follow these ideas, the tasks of interpreting the business environment will include the following, rather simple and practical issues: identifying events and trends from data, recognizing them as meaningful issues, and formulating an issue-list.

This list of tasks and issues is simple for a human information user to accept and judge. Most of the time experience and intuition will decide the choice of events and trends. If we want to build software agents to pursue the same activities, we will have to deal with a number of technical issues. In the following, we will try to make the operations needed a bit more precise and find out if they could be part of a support system for interpretation.

Judgement determines the probability of occurrence, the likely time of occurrence and the significance of each issue in order to forecast their development in the long run. Judgement is needed to investigate the causes of events and trends, if we cannot build any good causal models. Judgement has to be used to examine the interdependencies and cross-impact relationships between issues if we cannot build any good model for interdependence. Then judgement would be used in order to see if the occurrence of any events has an influence on the occurrence of others, and to judge the strength of the impact (totally determined, partially determined, have a common determinant, totally unrelated). In order to be more precise, (i) if the occurrence of event A enhances or inhibits the probability of event B occurring, or (ii) if event A has no effect, or (iii) if event A is an essential prerequisite for event B to occur. There are some possibilities to build and/or support this type of judgement with approximate reasoning schemes.

Judgement can be applied again to assess the impacts of major groups of issues on business (represented by selection criteria or performance measures) and to categorize issues as, for instance, crises, threats, and opportunities.

Issues are also evaluated in terms of whether they are emergent, evolving, or urgent, controllable or uncontrollable, whether their impacts are positive or negative, and if they bring potential gain or loss.

The *opportunity* category implies a positive situation in which a gain is likely (holding possibilities for future gain) and over which the company has a fair amount of control. Opportunities suggest chances of new markets or some advantages to the company.

The *threat* category implies a negative situation in which a loss is likely (holding possibilities for future loss) and over which the company has relatively little control. Threats tend to hinder the performance of the business or to keep the company from implementing its strategy and achieving its objectives. Threats increase the risk associated with implementing a strategy, they increase the resources required to implement a set of strategies, or they suggest that one or more strategies may no longer be appropriate.

A *crisis* needs urgent handling. It has an immediate and important impact on business operations. Issues that have zero impacts tend to stabilize the company's current strategy and operations, and are regarded as unimportant (Neubauer and Solomon, 1977; Dutton and Jackson, 1987; Jackson and Dutton, 1988; Schneider and Meyer, 1991).

When the issues have been evaluated, the next step is to rank and prioritize them and to formulate a strategic issue agenda. Issues are examined again in terms of the extent of their impacts on business (high, medium or low) and the probability of their occurrence. The issues are further ranked and prioritized in terms of their development (high, medium or low) as is shown in Fig. 6.4.

Issues that have a high impact and a high probability of occurrence have the highest priority for managerial attention. Issues that have a low impact on business and a low probability of occurrence have the lowest priority. Issues that have a high impact on business should be monitored closely and issues that have a low impact could be discarded.

When the issues have been ranked and prioritized, the final step is to propose action/reaction strategies. Issues that are *urgent* by nature and have a *high impact* need to be acted on immediately. Issues that have a *high impact*, but are *emergent* by nature, will be acted on later. *Unimportant* issues will call for no action.

There are three strategies for an interpreter, which usually can be employed for analyzing and interpreting data for the program of (i) assessing the impact of major issues on business, (ii) ranking and prioritizing them, and (iii) proposing action/reaction strategies:

- Data-driven strategy. The interpreter performs a broad-based search and actively looks for interesting and important events, as well as patterns, in the environment data.
- Goal-driven strategy. The interpreter develops hypothetic issues, seeks data support for the hypotheses, or, if a specific issue is known to exist, tries to find causes and reasons for the trends and events.
- Mixed strategy: an integrated use of both data driven and goal driven strategies (Bayer and Harter, 1991).

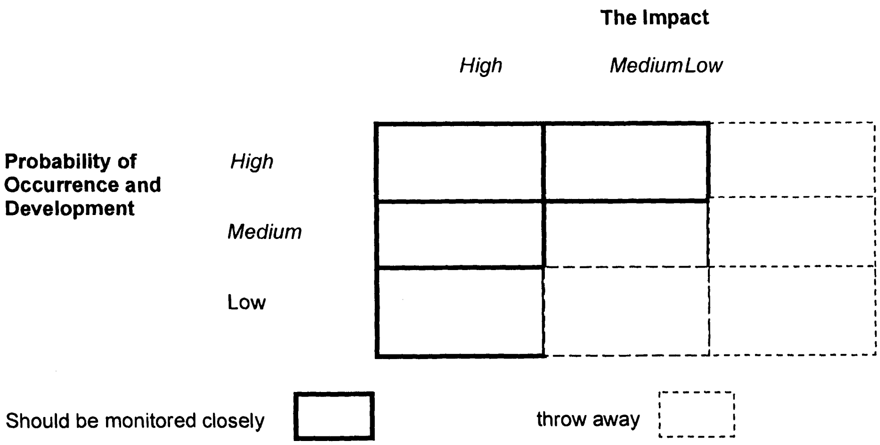


Figure 6.4. Prioritizing the issues.

In order to summarize - the interpretation agent could perhaps be built as an application and/or implementation of one of these three strategies. As we have seen in the preceding discussion, we need to solve a number of modeling and analysis problems on the way to making this agent a reality.

Mintzberg (1989) has found that managers normally combine analysis and intuition in their management activities: facts are worked on with analytical tools and then conclusions and decisions are arrived at trough intuition and experience. Mintzberg describes their thinking processes as highly inferential and intuitive by nature. Managerial cognitive activities are characterised by cognitive simplification and selective perception, which are guided by knowledge, experience and judgement.

A mental model is the representation, at the conceptual level, of a cognitive structure, of beliefs and knowledge in the head. It is a mental map that describes an interconnected set of understandings and assumptions about the business elements and their relationships, as well as implicit views of what one's interests and concerns are, what is important, what demands action and what does not. Managers develop simplified mental models of reality using only a small part of the information available (identified as approximate rationality), combined with prior knowledge, experience and premises (Durand et al, 1996). Mental models may remain static during certain periods, if there are no changes in the business context, but there should be effective routines for adapting and changing them in tune with changes in time and in the business context.

Mental models describe and explain the way in which a manager makes sense of and explains the world around him, i.e. the way in which he interprets his context of decision making and action. In his interpretation process, mental models are employed to synthesize data, to make sense out of data and to perform well-learned behaviour patterns. They are the underlying assumptions that actually link environment to strategy, data items to issues. Mental models help the manager to understand the external environment, as new information is understood in this framework of existing mental beliefs and models. The key factors and links described and explained in the mental model affect the types of information used to evaluate impacts or to interpret the information. This is also one of the reasons why interpretation may produce a distorted reproduction of information as it is processed through already established mental constructs. A new understanding of the environment may in turn trigger a change in the existing mental models. How various issues are interpreted, and what the quality of the interpretation will be, always depends on the interpreter's knowledge, his experience, his mental models and his ability at creative thinking.

Cognitive maps have been worked out as the explicit descriptions and computing implementations of mental models. Cognitive maps consist of nodes generically called "concepts" about different aspects of the environment and the cause-and-effect relationships between these concepts (cf. Durand (1996), Eden (1990)). Cognitive maps give us a method for structuring multiple - and sometimes conflicting - aspects of argumentation. They represent a designed scheme for addressing both the substance of issues, and for working with the knowledge and expertise surrounding issues. Cogni- tive maps, finally, give us a tool for capturing the different views of issues and for helping managers to focus on important aspects of the issues. They appear to be appropriate intermediates between mental models and specific, operational rules of interpretation.

There are software packages available for an implementation and use of cognitive maps, which will support users in building and using mental models. They are, however, intended to be interactive and it is hard to see how they could be made automatic as part of an interpretation agent. The mental models appear, however, to be useful for an understanding of what elements need to be part of an interpretation process.

Agent technology is a fast growing area of information technology - new agent-based products, applications and services are being announced on an almost daily basis. The reason for the interest is that the metaphor of autonomous problem solving entities, which co-operate and co-ordinate to achieve their desired objectives is an intuitive and natural way to conceptualise many problems. Moreover, the conceptual framework and the methods developed within agent technology provide a powerful and useful set of structures and processes for designing and building complex software applications (cf. Jennings and Wooldridge (1998)).

The inherent attributes of software agents make them useful for a number of information management tasks: scanning data sources, retrieving and cleaning data, and interpreting the data. Agents also have potentially many uses in executive support, for example, automated e-mail handling, meeting scheduling, web browsing, Internet news detecting and alert, external information gathering and filtering. In problems of automatically gathering, filtering and searching for information, the software agent approach represents one of the most popularly exploited solutions. In the environmental scanning activity of senior managers, the agent approach presents a novel way to supply information and to help conduct information acquisition. If we now add interpretation functionality to the gathering, filtering and searching for information we will add the possibilities to carry out advanced forms for collecting and summarizing data.

7.1 Industry Foresight

We have chosen industry foresight as the context for a closer study of knowledge management and the support of KM processes with agent technology.

Industry foresight is different from forecasting in the sense that there is not much use for time series analysis and mathematical modeling, it is knowledge based and works with experience. The reason for this is that the scope of a foresight lies 5 years ahead (in some cases even 10-15 years), which is equivalent with what forecasting people call "the emerging long term". Another reason is that we look for changing trends, or the emergence of new trends, and that the knowledge and the data we have available from past observations are not necessarily relevant or valid.

The UK Foresight program[4] is specified much along these lines. It is to develop vi- sions of the future, i.e. looking at possible future needs, opportunities and threats, and deciding what should be done now to make sure that we are ready for the upcoming new challenges. If we paraphrase the problem formulation used for the program for our present context, it would be something along the following lines:

It appears that the underlying task is to find a logical basis for industry foresight in the existing and potential, which includes two separate subtasks: (i) to find theoretical frameworks which can explain the scope and substance of this industry foresight, and (ii) to find methods and models for describing, explaining and predicting the development of key components causing changing trends or the emergence of new trends. This is, of course, an easy s tatement but a hard program to carry out.

The program carries with it a third task: (iii) to find good solutions with information systems technology to help users work with methods and models to create, to maintain, to modify and adapt, and to update reliable, good quality foresights. The IT solutions this requires should help the users' access to data sources and should support their work in such a way that they are more productive and effective when working on foresight reports.

A standard reference for work on industry foresight (and strategic planning issues) is the Hamel-Prahalad book *Competing for the Future* (1996). Although a number of points made in the book can and should be debated, it is a good reference as a theoretical framework for industry foresight.

Hamel and Prahalad identify the key needs to be satisfied with industry foresight methods as answers to the following three questions:

- What new types of customer benefits should we seek to provide in 5, 10 or 15 years?
- What new competencies will we need to build (or acquire) in order to offer those benefits to customers?
- How should we reconfigure the customer interface over the next several years?

If a company fails to develop (and then to understand and use) a good industry foresight, it will have some potentially disastrous consequences. There are a number of (sad) cases in a number of industries; here we will quote only two cases.

[4]http://193.82.159.123/documents.

IBM could not fully exploit the market created by the PC, which became a market standard; instead IBM gave a good start to companies like Intel and Microsoft, and later Compaq and Dell, which now are destroying the basis for IBM's erstwhile core business. IBM is implementing a new strategy built around its *e-Business* concept, which may become an effective counter-move to the producers of PC-based systems.

The Japanese car industry focused on quality, cycle time and flexibility - and spent 20 years to develop a sharp competitive edge in these factors. Now its competitors are on their way to spend an additional 20 years to catch up to a market formed by Japanese performance standards, which by the time they eventually catch up will be significantly different.

Hamel and Prahalad formulate some reasonable ideas on how to develop industry foresight, and we will build upon some of them here, as there are some empirical cases to show that they work.

We need to understand the key elements of intellectual leadership in an industry before we can hope to gain market leadership; thus, the work with industry foresight should be aimed at finding key elements of intellectual leadership.

In order to build sustainable competitive positions we must either be able to see opportunities or to exploit opportunities others have seen; thus, focus work on industry foresight on finding market opportunities.

As a way to build sustainable market positions, we can try acquisitions or "grass-root intrapreneurship". Still these approaches will not compensate for intellectual laziness and failures to see and comprehend the core competencies of the business. Thus, focus work on industry foresight to find changes in core competencies, which may significantly change sustainable market positions.

A way to understand how competitors operate is to follow up on how core competencies are exploited through new venture divisions, incubator projects and alliances with other companies with some specific, better foresights on supporting activities. Thus, focus work on industry foresight to follow up on competitor activities in this respect.

This list of four key focal points is not exhaustive but it is a good starting point to find the activities we need to support.

Hamel and Prahalad also offer some practical issues, which can be used as hints of what to look for when building an industry foresight:

- Find material, which can help to enlarge the opportunity horizon.
- Develop methods and collect data to find the white spaces in the market.

- Find ways to work from functionality thinking; do not collect material only on current products.
- Search for material, which will help to challenge price-performance assumptions.
- Find material, which can support you in a day-long debate on the following question: what are the forces already at work in this industry that have the potential to profoundly transform industry structure?
- Develop methods to collect data, which can help you to speculate on issues like: what is the impact of virtual reality on marketing means and methods?
- We need to find material to trace future trends in the intersection of changes in technology, lifestyles, regulation, demographics and geopolitics - products like the Nokia communicator can probably best be understood if the scope is wide enough.
- If we can find material to describe prevailing trends, we should also find ways to collect material for working out a contrary approach.
- If enough data and knowledge can be collected to trace and describe customer needs, we should look for ways to move beyond that and find out about unexplored opportunities.

Besides these more general and theoretical issues, there are very practical problems involved in working out the industry foresight. We should work out a reasonable scheme for how to find relevant data sources and to use them in the analysis. We need to design a support system for the users of these data sources, and we need to build user interfaces which will make it possible for them to use the system. We should remember to train the users so that they will be able to use and understand the knowledge, which is made available, and we should find ways to facilitate communication among the users and thus support the exchange of tacit knowledge.

In the UK Foresight program[5] the foresight process is formulated in much more specific terms:

- What could the future be like?
- What does this mean for me/us/the company?
- What should we do next?

[5]http://193.82.159.123/documents.

- Then what?

The foresight program when used in a corporate setting is envisioned to produce a number of benefits: (i) reduced risks and better rates of return for shareholders, (ii) new opportunities, (iii) more effective management, and (iv) a better strategic planning. This may well be the case, but experience shows that the instruments we use to work with the data to produce foresight visions and scenarios will have a significant impact on the quality of the foresight.

7.2 Agent Technology and Industry Foresight

We initially introduced the SwA and a number of features which defined its functionality. We will now refocus this functionality and work it out in terms of scanning agents (SA) and interpretation agents (IntA).

We will propose that the IntA should be used in tandem with the scenario agent (SA) and that both are multi-agent systems (MA), which are built as a group of collaborative agents. The group of IntA & SA agents will have a layered structure and the individual agents of the group will be either task agents (TA) or information agents (IA), the former category has a design which is dedicated to defined tasks, the latter category has design for monitoring and controlling the task agents (cf. Jennings and Wooldridge (1998)). The IntA & SA will be a *reactive* system, which maintains an ongoing interaction with the environment and will react to it by collecting data and interpreting them. The MA will be designed to deliver customised user-wanted data (information, knowledge) with interpretations, and the MA can be used as a wrapper around planning (or problem-solving, or decision) models for which we need to provide interpretations of their outputs.

The overall design of the IntA & SA follows four major design principles: (i) support for *open world* (OW) scenarios, (ii) support for *planning scenario* building, (iii) interpretation support for planning models, and (iv) interpretation support for data collected in a data warehouse.

In the first case scenarios are built with support from the MA system and used both for independent scenario planning and as a basis and input for the planning models (as the scenario material is stored in the DW). Interpretations should be produced to fa- cilitate the scenario building process.

In the second case, the planning scenarios are built to drive models and (a) input data is produced to the model standards and/or (b) is combined with planning model outputs to be used as input to other planning models (and should thus follow the model standards). Interpretations should be produced to facilitate the choice of planning models, and in order to explain the scenario results produced with the models.

In the third case, interpretations support work with the input data to planning models and help to explain the results to recipients of reports. In the fourth and final case, interpretations help to quickly make sense of large sets of data collected in a data warehouse.

The planning scenarios can be of two types. A subset of *OW scenarios*, which possibly have been refocused and which have been made more specific and/or have been simplified with the help of SA support. *Tailor-built scenarios*, which have been produced to run plannin g models (single models or a system of models) as part of a strategy to sketch out future developments of the business context. The second type of planning scenarios represents projections of an understanding of the business context based on the knowledge we have on the past and the present, and should be run with data from the DW. The first type of scenarios will - relative to this - have more futuristic elements and may be more difficult to adjust to the planning model standards as they will run with data generated for the OW scenarios. Consequently, there are differences in the interpretation tasks assigned to the IntA: in the first case "open categories" of elements and in the second case "planning model-specified categories".

The construction of OW scenarios, and the application of scenarios to planning models, is part of the process to build the industry foresight. An essential part of the foresight-building process is to handle large amounts of inconsistent data in a systematic and effective way. The necessary support for that is to quickly scan and use data from many (tens, hundreds of) data sources, to interpret the data and to summarize findings and insights in a form, which can be used in the verbal storyline part of both OW and planning scenarios. Interpretations add value to the data gathering and cleaning carried out by the SA, and hence we may look at the IntA as a value-added service to the SA.

Neither OW scenarios nor planning scenarios should be one-off constructs. Scenarios, when found relevant and useful, should be used repeatedly to support rational reactions to a changing environment. Then, for this the IntA & SA should help evaluate and interpret sudden developments, breaking news and significant changes to the environment.

7.3 Interpretation Support for OW Scenarios

When we build the IntA & SA agents to support the building and the use of OW scenarios, the main emphasis will be on: (i) collecting data from identified data sources (in the DW, on Internet or on an intranet), (ii) cleaning and condensing the data as information, (iii) interpreting the data, which has been collected and condensed, (iv) combining data from different types of data sources, (v) supporting the use of data sources which have been built and used manually, (vi) supporting the use of database or data warehouse depositories, and (vii) supporting the extraction, editing and interpretation of data (information, knowledge) for the verbal storyline of an OW scenario.

The SA for OW scenarios is a search agent (a scanning agent with enhanced functionality), which also supports data insertion in a database/data warehouse, the handling of a database/data warehouse and the editing and writing of OW scenario reports. The IntA for OW scenarios works with reference points and benchmarks to classify observations as *crises, opportunities* or *threats.*

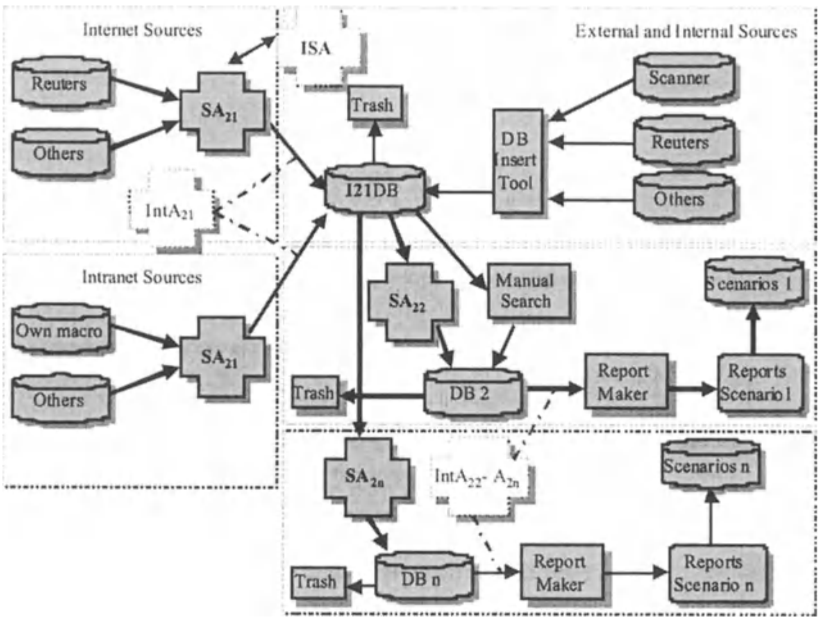


Figure 6.5. A layout of the IntA & SA for support of OW scenarios.

The functionality of this part of the system can be summarised as follows (the IntA parts are shown with italics):

- IntA21 & SA21.

  - Collects data from different sources on the Internet and from various intranet sources.

  - Can work with Internet sources that are password protected;

- Analyses the data based on its content; handles text and numerical data;

- *Interprets the data with the help of benchmarks and reference points stored in the I21 DB, or which are given as input data by the user*;

- Stores interesting data in a data warehouse application

- *Stores interpretations (linked to the data)*;

- Retrieves only new and changed data;

- Builds meta-data on retrieved data to follow up on retrieval;

- Scans different data sources and sites frequently for new data;

- Represents an effective use of data sources, which in fact is faster than human users;

- *Collaborates with IntA10 & SA1 through coordination with the ISA* (an IA for the SAs, i.e. an information agent developed for the scanning agents);

- IntA22 & SA22 - IntA2n & SA2n.

  - Analyses and collects data on selected topics based on user-defined profiles;

  - Sorts the data based on date, content and profiles;

  - *Interprets the data with the help of benchmarks and reference points stored in the DB*;

  - Sorted data which is related is stored together in DB2 - DBn;

- Report Maker.

  - Allows the user to select data from profile-defined folders;

  - *Interpretations can be retrieved with the data*;

  - Selected data can be edited and saved as reports;

  - Edited data can be traced to the unmodified (original) data if needed;

The interpretation agents to be used for the OW scenario building support will have a generic basic layout and adaptive elements in order to fit them into their specific task environments (cf. IntA21 and IntA22 - IntA2n).

One of the basic ideas we had with the design of the SA was to use Internet extensively as a data source for the OW scenarios. In the last 2 years, we have carried out a series of studies with search agents on Internet data sources, and we have found that the quality of the data retrieved was not very good. The insights, which could be collected from publicly avilable data sources, were not very profound and repetitions of the same material from different data sources were frequent. We also carried out a series of experiments with the *Reuters Business Briefing* (as well as with other commercial data sources; RBI is now replaced by *Factiva*), which showed that the quality of data was much better. These observations have some relevance also for the design and use of the IntA: interpretation of inconsistent data (as can be found from public Internet data sources) is not a very worthwhile effort, the chances for success are much better when working with consistent data. This supports the use of either commercial Internet services for the building of OW scenarios or internal, evaluated and validated data sources.

7.4 Interpretation Support for Planning Scenarios

For the planning scenarios, we work with a special agent construct called SA1. For interpretation purposes the agent will be working with:

- IntA10 , which is interpreting the data to be used as input to the models of the planning scenarios;
- IntA11 , which is interpreting the output from the planning scenarios; the interpretations can then be stored with the output;
- IntA12, which provides one further interpretation after the planning scenario material has been enhanced with material from the manual search.

As the IntA1 & SA1 supports the building and use of planning scenarios, there is a more focused use of data sources than for the OW scenarios. The primary data source is the DB, which holds primary data for the MA system or (if the OW scenarios have been run first) scenario data from different data sources. A third possibility is that the systems user wants to add data of his own, which is then to be used for new versions of the planning scenarios.

The support offered by the IntA1 & SA1 is more focused, but it is basically the same as for the OW scenario:

(i) collecting data from identified data sources (in the DW, on Internet or on an intranet),

(ii) cleaning and condensing the data as information,

(iii) interpreting the data, which has been collected and condensed,

(iv) combining data from different types of data sources,

(v) supporting the use of data sources which have been built and used manually,

(vi) supporting the use of database or data warehouse depositories, and

(vii) supporting the extraction, editing and interpretation of data (information, knowledge) for the verbal storyline of a planning scenario

The IntA1 & SA1 for planning scenarios is a database/data warehouse handling and data interpretation agent, which collects data, interprets selected parts of the data and inputs data into planning models, runs them, interprets the results, stores the result in the DB (or in a data warehouse application) and supports the writing of scenario reports.

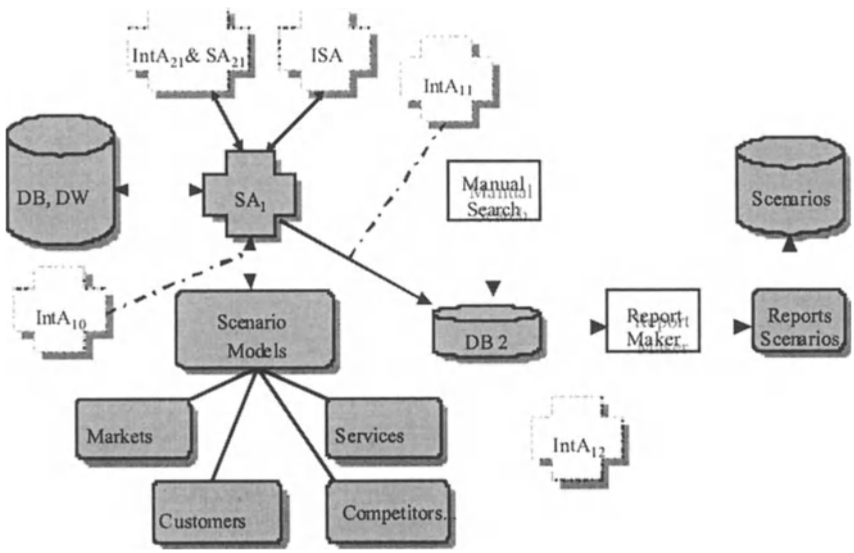


Figure 6.6. A layout of the IntA1 & SA1 for planning scenarios.

The functionality of this part of the system can be summarised as follows (the IntA parts are shown with italics):

- IntA1 & SA1.

  - Activated through data-generated events, events connected to time or user- generated events;

  - Works as an information customiser, i.e. it collects, scrubs, integrates and transforms data for the scenario-building models from the DB or DW;

- *Interprets selected parts of the data through IntA10*;

- Provides help desk support;

- Offers level of support (novice, intermediate, experienced, advanced);

depending on choice the support can be either an off-line help function or an autonomous information customizer and help desk;

- Runs planning models with data elements of the DB,

- *Interprets the planning scenario results with IntA11*;

- Stores intermediate results in DB2 (part of the DB),

- *Interprets the planning scenario results, after adding the results of the manual search, with IntA12*;

- Runs a Report Maker (which support the user in making a scenario) and,

- Stores scenarios in a DB.

- Collaborates with IntA21 & SA21 through co-ordination by the ISA;

In addition to the individual agent features we have just worked through there is some work done on creating a class of *collaborative agents*, which will have both individual features and features they get through the collaboration. Collaborative agents emphasise autonomy and co-operation with other agents in order to perform tasks for their users in open and time-constrained multi-agent environments. These features are relevant also for interpretation tasks, in which we may have agents to work out interpretations of selected parts of material from a data warehouse. This can also be done for specified parts of material produced with OW and planning scenarios. Then the IntA should be able to combine these interpretations to some consistent scenarios through the collaboration. It is probably needless to state that the consistency will be manageable only through interaction with a knowledgeable and experienced user. Also the IntA1 may have some (limited parametric) learning properties and they may have to "negotiate" in order to reach mutually acceptable agreements.

The motives for building collaborative agent systems include:

- Solving problems that may be too large for a centralised single agent,
- Allowing for the interconnecting and interoperation of existing legacy systems (e.g. decision support systems, conventional software systems, etc.), and,
- Providing solutions to inherently distributed problems, such as drawing on distributed data sources or distributed sensor networks. With interpretation agents we may add one more motive:

- Interpretations can be run in parallel on carious parts of large data sets and then combined to form a quick and effective summary.

The functionality of this part of the system can be summarised as follows:

- ISA.

  - Operates as an IA in relation to SAland SA2.

  - IntA1 is context adapted to planning scenarios and works in tandem with SA1.

  - Each IntA2j is context adapted and is designed to work in tandem with a SA2j .

  - SA2 operates as an IA in relation to SA21 - SA2n.

  - All the SA21 - SA2n are designed as TAs.

  - All the IntA21 - IntA2n are designed as TAs.

  - Co-ordinates both interpretation and scenario agents, which requires multifunctionality.

The world of collaborative agents is being extended to the multiagent (MA) systems, which allow sets of agents with differing capabilities to interact to solve problems, they allow for scalability, they permit us to reuse software modules, they handle software evolution and they promote open systems. The complex tasks assigned to the ISA favour the use of an MA approach.

Virtual enterprises build on MA systems, which monitor and control business and manufacturing processes. In this context the problem of coherence has become visible, i.e. how different activities in a distributed system consisting of heterogeneous and autonomous parts relate to each other. In this sense, working on coherence is moving beyond interoperating as it considers the global structure of different activities, not just the exchange of data among them.

The summarising of interpretations, which have been made with collaborative IntAs, is a good point in case for coherence (albeit a bit hard to achieve). The DARPA and the Lycos systems represent approaches to deal with coherence, and similar tasks have been pursued in studies of human-agent interaction and in games to mimic real-life markets. We will have to find ways to deal with the coherence problems, not only for the technical summaries but also for the semantic interpretations.

For MA systems of IntA & SA pairs to succeed, a systematic collaboration of agents is necessary. This, again, requires that the agents have been designed and built in such a way that the internal cognitive structure of the agents is conducive to collaboration. If this is the case, then there is a basis for building MA systems with some learning and planning capabilities. As these capabilities are part of the hype surrounding the use of intelligent technologies we need to point out that the learning and planning capabilities reside in the interaction of agents and probably not with the individual agents.

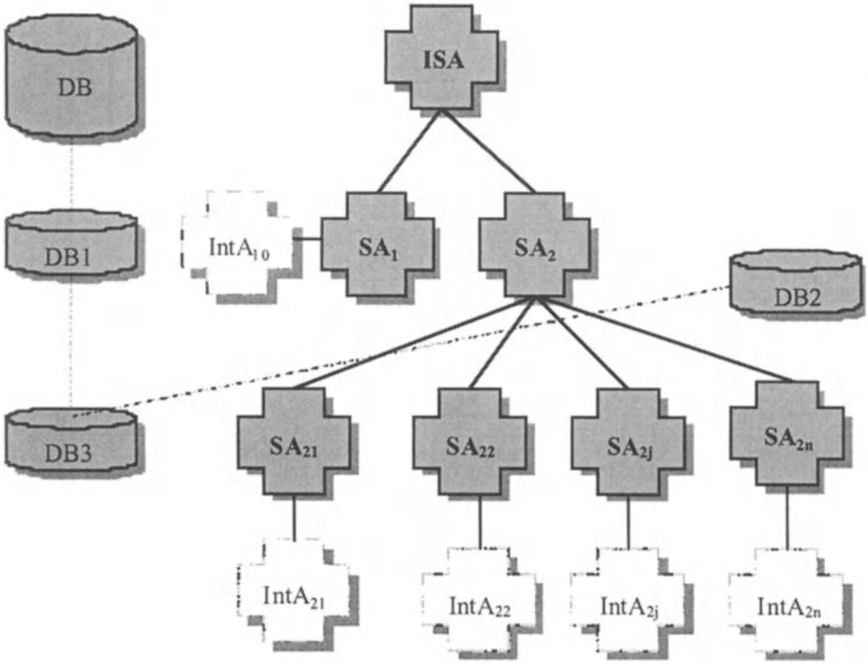


Figure 6.7. Layout of the IntA & SA as collaborative agents.

The IntA, in its various forms of IntA10, IntA11, IntA12, IntA21 - IntA2n, should be an MA system of collaborative agents itself, which (i) interact to produce interpretations in support of OW and planning scenarios, (ii) allow scalability from small to large data sets, and (iii) are built by reusing software modules - which should follow a software evolution strategy.

7.5 Interpretation Support for Planning Models

Besides the use of the IntAj & SAj pairs as interpretation support within an MA, the agent functionality also allows for simpler applications as interpretation support for selected planning models.

In the following, we have outlined a construct in which agent pairs work with planning models as more or less stand-alone applications. The ScA1 is now the search agent part of the scenario agent SA, and the IntAj are simplified interpretation agents adapted to the selected models.

The functionality of the support provided by the pairs of agents for planning models can be summarised as follows (the IntA parts are shown with italics):

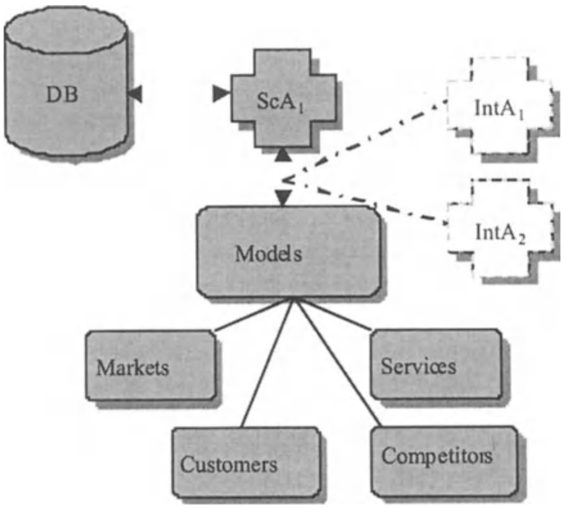


Figure 6.8. Layout of the IntAj & ScA1 for planning models.

- IntAj & ScA1.

  - Activated through data-generated events, events connected to time or user-generated events;

  - Works as an information customiser, i.e. it collects, scrubs, integrates and transforms data for selected planning models from the DB;

  - *Interprets selected parts of the data through IntA1*;

  - Provides help desk support;

  - Offers level of support (novice, intermediate, experienced, advanced); depending on choice the support can be either an off-line help function or an autonomous information customiser and help desk;

  - Runs planning models with data elements of the DB,

  - *Interprets the planning model results with IntA2*;

Let us the find out how the IntA functionality can be applied for a planning model. We have selected a generic model for an *Estimation of likely future market potential* as an example, and will in the following show how the IntA should be implemented in this context.

The set of countries to be chosen is defined as a function of market potential and prices. The IntA1 is used to interpret these data (cf. fig. 9) with linguistic categories such as ["small" - "great"] for market potential, and ["low - "high"] for prices.

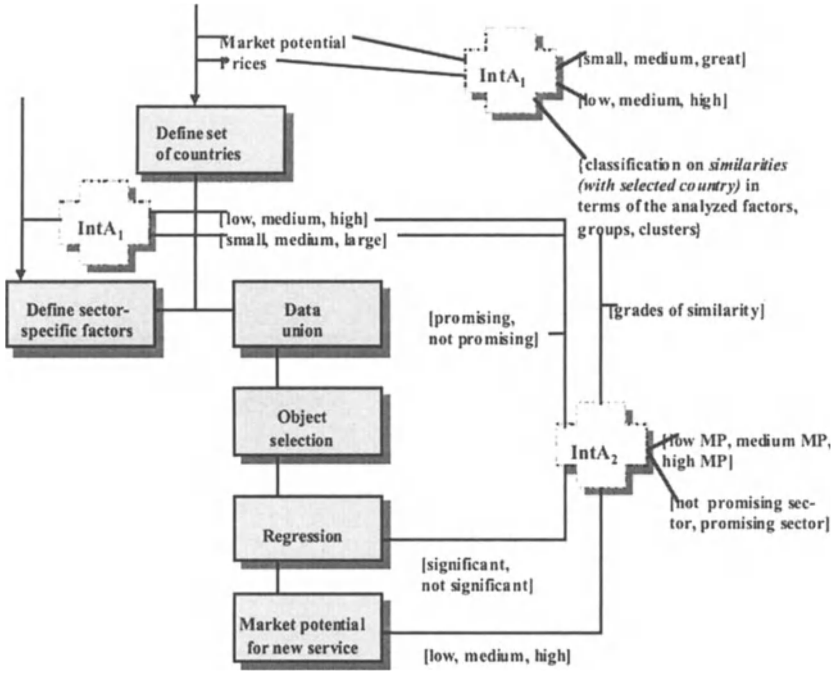


Figure 6.9. The interpretation agents and a planning model

In this way, it is possible to classify countries according to *similarities* in terms of the analyzed factors, and then to find groups and clusters of countries. This classification is one of the inputs for IntA2, which will use the *grades of similarity*, the classifications of sector-specific factors (which may be multiple attribute, linguistic classifications), the results of the regression analysis (which are interpreted in grades of *significant/non-significant*) and the model output on the market potential for the new service (which is interpreted in grades of [low, medium, high]).

The output of IntA2 is a classification of the market potential for countries and sectors in terms of a combination of a [low, medium, high] market potential and [promising, not promising] sectors.

7.6 Interpretation Support for Data Sources

In a similar fashion as the interpretation agents for planning models, we may also use simplified versions of the scenario and interpretation agents to build interpretation support for the use of various data sources. Again we will use the search agent part of the scenario agent SA and fit IntAs to them, which will be context-adapted to selected data sources.

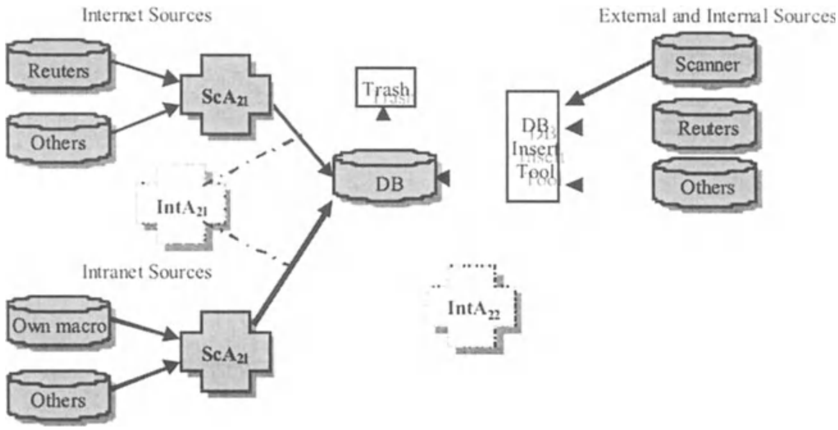


Figure 6.10. Layout of the IntAj & ScAj for data sources.

The functionality of interpretation support for data sources can be summarised as follows (the IntA parts are shown with italics):

- IntA21 & ScA21.

  - Collects data from different sources on the Internet and from various intranet sources.

  - Can work with Internet sources that are password protected;

  - Analyses the data based on its content; handles text and numerical data;

  - *Interprets the data with the help of benchmarks and reference points stored in the DB (DW), or which are given as input data by the user*;

  - Stores interesting data in a data warehouse application;

- *Stores interpretations (linked to the data)*;
- Retrieves only new and changed data;
- Builds meta-data on retrieved data to follow up on retrieval;
- Scans different data sources and sites frequently for new data;
- Represents an effective use of data sources, which in fact is faster than human users;

■ IntA22.

- *Interprets the data with the help of benchmarks and reference points stored in the DB (DW)*;
- *Sorted and interpreted data which is related is stored together in the DB(DW).*

7.7 Generic Interpretation of Agent Structures

It has probably become evident in Sections 7.3-7.6 that the interpretation agents have a common generic core in their designs. The interpretation agent IntA21, working in tandem with the search agent ScA21, will,

- collect data from different sources on the Internet, and from various intranet sources;
- analyse the data based on its content; handles text and numerical data;
- interpret the data with the help of benchmarks and reference points stored in the DB, or which are given as input data by the user;
- store interesting data in a data warehouse application;
- store interpretations (linked to the data);
- retrieve only new and changed data;
- build meta-data on retrieved data to follow up on retrieval;
- scan different data sources and sites frequently for new data;

This is actually the same functionality as that of IntA21, even if this agent works in the context of inserted, not scanned data. Furthermore, it is generically the same agent as the IntA21 in Fig. 6.5, even if the latter has some added functionality in order to deal with the collaborative environment.

The interpretation agents IntA1 and IntA2 (cf. Fig. 6.8) have the same generic structure as the data they should work with is specified as input/output data for/from planning models. The IntA10 and IntA11 agents of Fig. 6.6 will have the same generic structure unless the planning models used in scenarios will have very diverse conceptual structures from the selection made for the models.

The logic part of the agents can probably be built with the same fuzzy logic & approximate reasoning schemes for all interpretation agents, but the event adapters need to be tailored to the specific agent contexts: (i) OW scenarios, (ii) planning scenarios, (iii) planning models, (iv) Internet, intranet and internal data sources, (v) collaborative agent environments and (vi) co-operative, ISA-controlled efforts. In this sense, the interpretation agents are partly generic and partly specific, context-adapted.

7.8 Approximate Reasoning and Sense-Making

The use of fuzzy logic and fuzzy reasoning methods (which we referred to as the logic part of the agents in Section 7.6) are becoming more and more popular in intelligent information systems, especially in hyperknowledge support systems, knowledge formation processes in knowledge-based systems, active decision support systems, medical support systems, robotics, financial analyses, and control and pattern recognition.

As we outlined the basic functionality of the IntA we used normal/unusual and plausible/implausible as descriptions of events and as labels to be attached to events, observations, results, etc. as part of the interpretation process. It should be clear that these labels are linguistic and imprecise, and that they cannot be found through any precise mathematical analysis, neither would we like them to be assigned by a user in a subjective fashion.

Elsewhere we have made the case for the use of fuzzy sets and fuzzy logic if we want to be both imprecise and systematic when we interpret events and observations in a business context. It should be obvious, that industry foresight is a context where we cannot be precise in observations or interpretations of data, information or knowledge. In Chapter 2 we have quickly summarized some parts of a background in fuzzy sets, fuzzy logic and approximate reasoning needed for the functionality of the IntA constructs.

7.9 Scenario Lite: Foresight and Agent Software

The SA functionality, which has been described in the previous sections, has been implemented in a software agent system. The evolving foresight is built as a storyline, which is fed by the SA from a number of selected data sources. The SA is a multi-agent system and as each SAi is working on one (or several) data sources with its profiles - there is at least one profile specified, adapted and updated by the SAi for each data source.

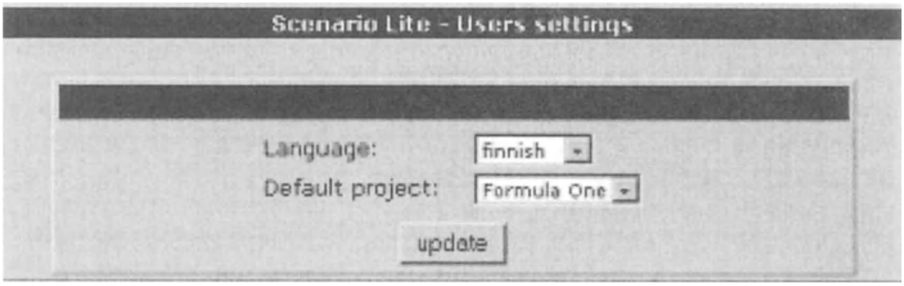
The multi-agent system can be used with tens or hundreds of data sources, which are scanned and harvested automatically at pre-selected times or with pre-defined intervals.

The SAi decides if the material which fits the profile and is being harvested is new or not; only in the former case it is collected and sorted into the correct category and stored in the data warehouse where it is linked to the correct place in the storyline.

In the following we will (very) briefly work through the *Scenario Lite* in order to study the setup and the functionality of the agent technology.

User settings

In the users settings menu the choice of language used in Scenario Lite is defined. The default project used can also be changed here.



Project Administration

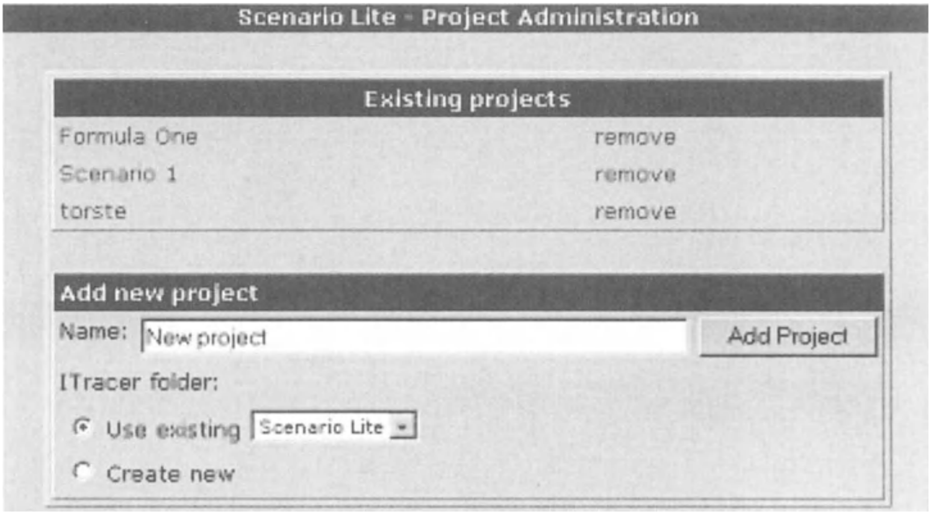
The Project Administration functions keep track of projects, which run storylines and controls the adding of new projects. There are several versions of the SAi, the Scenario Lite is indicated as the agent system to be used.

<u>Existing projects</u>

On the project administration page current projects can be removed by clicking the corresponding remove link.

<u>Adding new projects</u>

To add new projects simply enter a name for the project and select which folder it should be in. When the selections have been made they are activated by simply clicking the Add Project button to finish the process. The new project name is now visible in the Existing projects table. It is also possible to create a new folder for projects.



View Documents mode

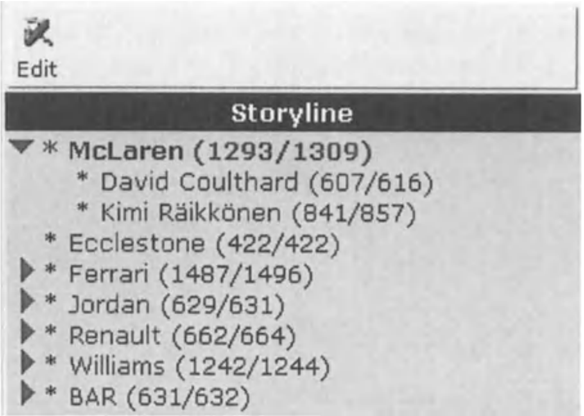
Changing between projects can be done by selecting another project from the dropdown menu. The View Documents mode has two selections, one for viewing and one for editing the Storyline.

Viewing documents

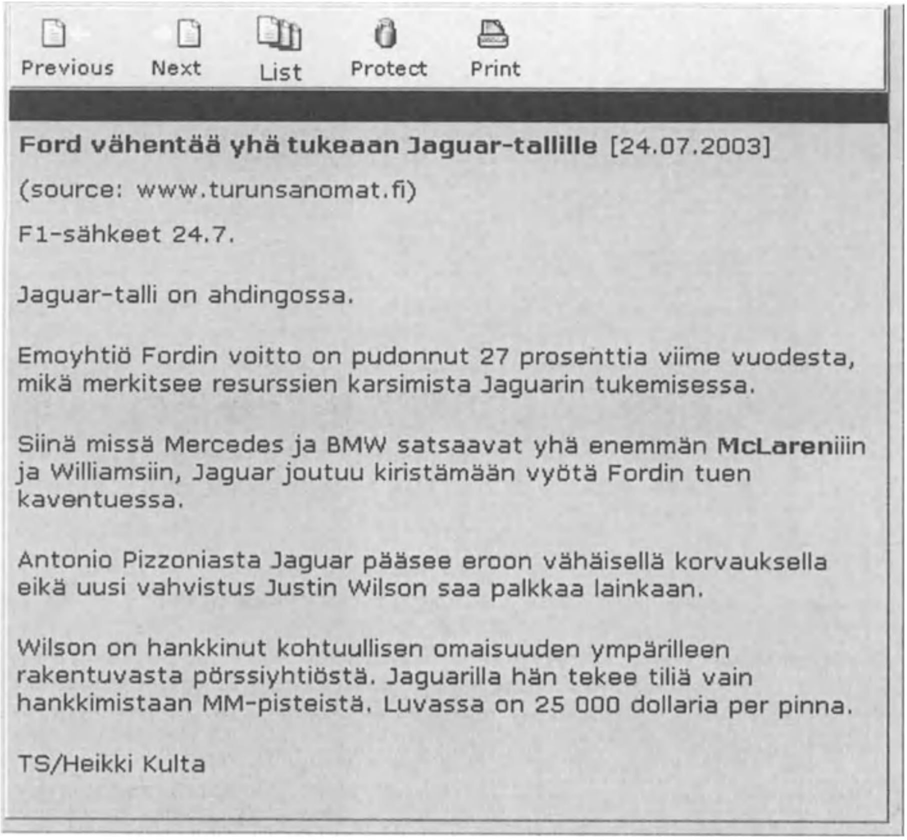
By clicking a header in the Storyline tree, the documents for that header and its subtitles will be shown. The documents will be shown in the table on the right hand side. By clicking the header again the subtitles will be hidden.

The numbers after the header show how many unread documents there are among all existing documents. The arrows on the left hand side can be red or black; if they are black there are no unread documents; if they are red there are unread documents.

By selecting a visible document it is possible to view the whole document. It is also possible to sort the documents by date or by header by clicking either Date or Headline. Here it is possible to turn an Advanced filter on or off by clicking the Turn on/off advanced filter. If the user only wishes to see unread documents he can select the Show only unread mode. The same goes for if he wishes to see only protected documents.



The document

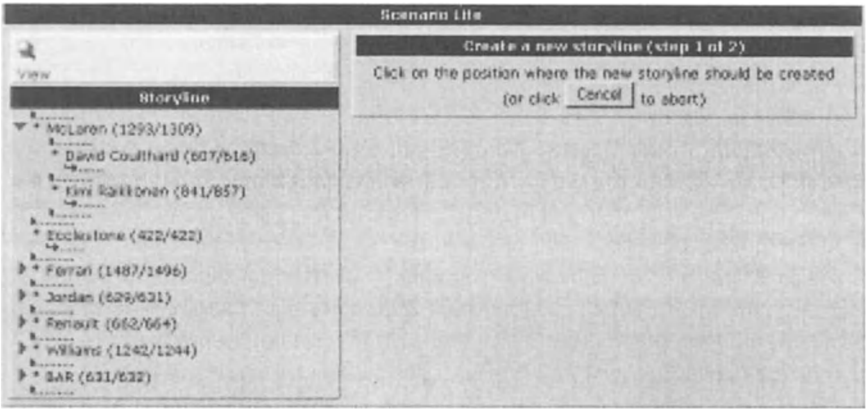


When viewing a specific document there are certain actions that can be made. The document can be protected, which means that it cannot be removed.

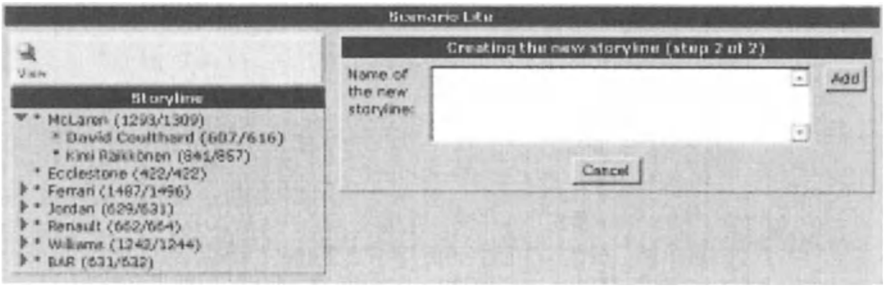
By clicking Print a printer friendly version of the document will be shown and printed. The List option takes us back to the list view of all documents. With the next and previous buttons it is possible to navigate between documents.

Edit mode

In the edit mode it is possible to add new storylines to the storyline tree. This is done by clicking on the New button.

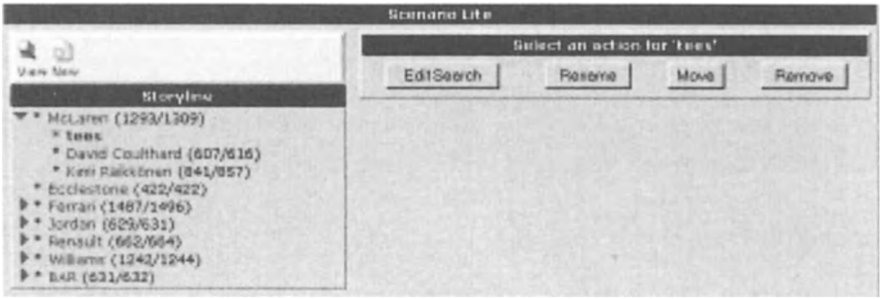


The next step is to select where the new storyline should be placed, this can be done by selecting one of the available positions.



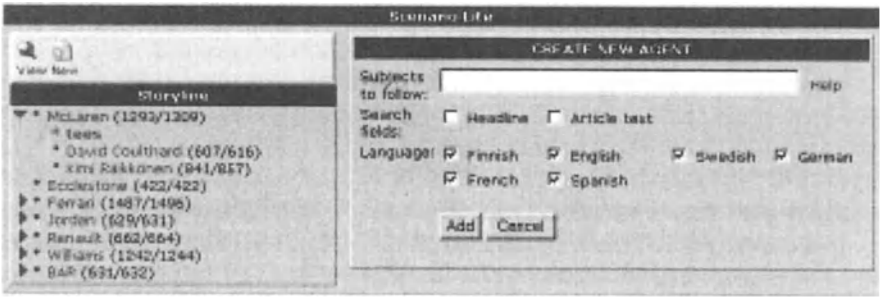
The next step is to give the storyline a name by entering it into the textbox and clicking the add button. Now the new storyline should appear in the tree.

If one of the existing storylines is selected in the Edit mode there are some operations that can be made on them.



<u>Edit Search</u>

If you wish to edit the search criteria (of the profile) for this storyline simply click the Edit Search button.



Here you can enter the keywords for the search and if you wish the agent to look for these keywords in the header, the body text of the article or both. The search engine uses Boolean logic (AND, OR, NOT), parenthesis: (), hyphens: -, and asterisks: $*$.

The following rules apply for this:

- SPACE between words equals AND operator. Ex. Bill Gates = Bill AND Gates. This means both words must be present in the document.

- If we have Bill OR Gates then both words need not be present in the document.

- By using NOT in front of a word it will be excluded and documents containing that word will not be searched.

- The asterisk (∗) works like a wild card. Ex Micro* will retrieve all documents containing words that start with Micro- i.e. Microsoft, Microscope etc.
- If we use hyphens then the words must be found in that order. "Bill Gates" means that there cannot be any text between Bill and Gates.

Some examples:

- "happy AND (dog OR cat)", is the same as "happy (dog OR cat)"
- "happy dog"
- "(foo OR bar) AND (baz OR boo)"
- "((a OR b) AND NOT c) OR d)"
- "(apple "steve jobs") AND NOT (banana OR orange OR pear)"
- "(NOT ball) AND luc*"

<u>Rename</u>
Click the rename button if you wish to rename the selected storyline.
<u>Move</u>
Click the move button and choose where you wish to move the selected storyline.
<u>Remove</u>
Click the remove button if you wish to remove the selected storyline.

The "lessons learned" on support technology for knowledge management we collected above in Section 6 referred to the experience we have of working with the SA agent system as part of a KM project. We will once more summarize the technical experience we collected with the agent software:

- KM can be handled with web-based, practical, simple, inexpensive applications for improving everyday activities
- Robust KM systems can be built and implemented with standard software
- KM should be problem-driven rather than technology-driven; technology cannot deliver KM
- KM technology is an enabler; should address the daily needs of its potential users
- KM technology should be used to connect people to data, information and knowledge - and to other people (much knowledge is tacit)

- KM tools should be built on existing information and communication architectures, i.e. the existing infrastructure
- KM and its support technology should be embedded in work processes with the users in control of the tools and the applications

There is an obvious potential in using this type of technology for KM support functions.

7.10 Case Studies

In this Section we have collected several case studies which illustrate how KM projects have been run in organizations. The studies cover both service and manufacturing sectors and personalization and codification strategies. They also illustrate the specific categories of KM projects (KM repositories, KM transfer and building a KM infrastructure) we have been discussing above. None of the case studies shows any implementation of fuzzy intelligent systems (so far).

7.10.1 Complex Adaptive Systems for Managing Organizational Knowledge

Case Study of McKinsey & Company[6]

McKinsey & Company is a consulting firm headquartered in New York City and with a presence in 44 countries with about 8,000 advisors. McKinsey is particularly interested in knowledge management (KM) and has during the last twenty years developed both significant expertise in knowledge management and has also worked with different KM strategies.

The Problems

In 1987, as a result of a worldwide diagnostic exercise, McKinsey & Company found that they were missing huge opportunities for providing better services to customers, because they were not taking advantage of what the company collectively knew. To this aim, they needed to make their internal market of knowledge sharing work better. In particular, they needed to create a classification scheme that could adequately describe the firm's research and consulting work, to label the specific kinds of in-house management consulting experience and to collect them. They also needed a classification scheme that was able to keep categories flexible, but still standardized so as to facilitate the information recognition.

[6]The European KM Community, www.knowledgeboard.com.

Solutions

The solution to these problems was found during the execution of a project called "*Genoma*" (1998) that was aimed at creating a map of the organization's knowledge base. The original goal of the project was to create a large knowledge base of readings accessible through the Web. After a few months of the project changed direction towards a complex adaptive system (CAS) model. The CAS model is based on three fundamental principles:

- No central decision-maker can know all the facets of the entire organization and consequently can be able to develop all the relevant categories
- Good classifications should be non-permanent by nature
- The existence of different points of view about relevant categories is an opportunity to stimulate debates so as to foster creativity and innovation

Implementation Method

First the company developed a functional and static knowledge classification system. This created a number of problems such as semantic overlaps, the creation of new terms and the discarding of old ones and pressure by some groups to make the terms they used to be shared by the whole company. During the development and implementation of the Genoma project, McKinsey's managers decided to accept the CAS principles.

They abandoned the old, mechanic view of the organization and embraced an organic and adaptive view, which works with emerging knowledge. What was first considered a problem was later seen as a resource and an opportunity to boost creativity and innovation. In particular, managers decided to:

- split every team into multiple sub-teams: each of them was responsible for a "sub-domain" of knowledge (in that way, several smaller web-sites on leadership, organization design, culture, and management processes were created)
- encourage each sub-team to form communities of practitioners; the communities had to create their own map of the knowledge in which they had a professional interest
- embrace the inherent redundancy of the web technology: by encouraging each sub-team to create links to relevant sources (and people,

via personal home pages), they fostered the creation of many overlapping networks of knowledge

- create a working philosophy and a team culture based on the concepts of revision and change, gaining a continuous feedback from the market (via usage reports) so as to allow a process of organic self-organization
- encourage the creation of a self-appointed steering committee that had to maintain some workable limit on the overall number of terms and maps in domain communities

In any case there was some freedom for new domains to be created and linked to the project as well as for domains to be consolidated and recombined according to the "voice of the market".

Key Factors

The key factors of the project implementation were recognized in the creation of building blocks (i.e. pieces of previous experience), the aggregation of individuals both in formal and informal groups, the flow of information and resources, and the tagging of pieces of experience. With the help of these factors, the company was able to create a network of consultants and knowledge resources, which were self-organized around different nodes of codified and people-based knowledge.

7.10.2 Knowledge Repositories

Case Truffles & OgilvyOne

The following OgilvyOne -case is written by Kevin Cody (Cody, 2001). OgilvyOne is one of the largest marketing communications networks in the world. They serve more Fortune Global 500 companies in five or more countries than any other agency. They had a desire to share knowledge and the project for doing that was initiated by the chairman himself. They developed a system called "Truffles". The name originated from a quote by the David Ogilvy, "we purse knowledge the way a pig pursues truffles".

The development of Truffles is concentrated around three areas: content, usage and application. These areas are, of course, interlinked but to ensure that no area is overlooked there were three distinct groups looking at each of these areas.

The content of Truffles is produced by the users. To ensure the validity of the knowledge objects, or Truffles, as they call them, a knowledge manager checks and edits the material and publishes it in the system. The material can be a case study, an article or a TV advertisement.

After an item has been published, the application manages some other tasks automatically. It decides where the knowledge should appear, in which communities it should appear and who should be notified that it has been posted. This is possible because the users have to register in the system and provide information about their skills and interests.

The users can publish their biographies in the system, which will help other users to find people who do similar work. In order to promote co-operation among employees around similar interests, Truffles has a tool called "communities of interest". This supports the users with documents related to the community, a specific discussion group and a list of the community members. One significant thing about Truffles is that it isn't exclusive. It provides information to everybody and users can join all the communities they wish.

The use of Truffles is widely encouraged inside OgilvyOne. While the company is using traditional marketing methods, such as posters and e-mail campaigns, it also uses a stick and carrot approach. Truffles is monitored and part of the yearly bonus is tied to the activity on Truffles. Every activity that OgilvyOne does today includes Truffles-elements. Almost 80 percent of the personnel has registered as Truffles users.

The Truffles application itself has developed over time and is actually improved on a continuous basis. First there was a problem with the content. The users felt that there was too much of it and did not think the system was meant for them. The solution was to implement a personalized front page and to create the communities of interest. In the most recent version of Truffles there is support for users to access the system through both a PDA or a WAP phone.

7.10.3 Collecting and Reusing Tacit Knowledge

Case Tamglass

Tamglass designs, manufactures and markets safety glass machinery for the architectural, appliance and automotive glass industries. Tamglass Group has customer service offices and manufacturing, together with a network of sales agencies, in all main market areas. The company has delivered over 1,400 safety glass production lines to over 70 countries during its 30 years of operation. Measured in terms of net sales and the number of machines delivered, the company is the world's leading manufacturer of safety glass machinery.

Tamglass aimed to shorten the delivery time of new production lines by collecting and reusing tacit knowledge which was created, enhanced and used while installing the production lines. An average project to deliver a glass-processing machine takes from 5 to 10 weeks, and if the process can be shortened by 10 percent, considerable savings can be achieved. In the same way reusing knowledge could shorten maintenance time.

A Finnish company, Toyme Lab (www.toymelab.com), delivers the application for storing the knowledge with software which is developed for capturing and storing tacit knowledge.

The application is used by field-workers, who report and write about the work they have done. Tamglass uses the application with portable computers, but it can be used with mobile phones or PDAs as well.

Tamglass has piloted the application and is planning to continue to use it. It is too early to state how much working time has been saved, but the most important result is that knowledge is stored somewhere else than in only the heads of the maintenance workers.

7.10.4 Technology Intelligence - Following the Markets and Internal Knowledge

Case Sonera

Sonera Corporation is a leading provider of mobile and advanced telecommunications services. It has a revenue of 2.2 billion Euro and has about 7 400 employees. In order to follow what is happening in different technologies and at the same time to keep track of who knows what inside the company Sonera has created a Technology Intelligence (TI) network.

Another reason for the TI-network is that there are many people who work with the same kind of issues independently of each other and the TI-network will help them to leverage their knowledge.

The basic idea is to create a network of people who work with different new technologies and help them interact which each other. The goal is to keep track of long-term technological trends and to carry out necessary ad-hoc analyses for urgent cases for which the TI can find people who work with relevant issues. The knowledge provided by the TI is used for the quarterly strategy process.

In practice some people from different parts of the organization are chosen as agents and are charged with the task to follow different technologies. They basically carry out their daily work and at the same time they pay attention to specific types and sources of information. They report their findings to the TI-web site. The TI presented in Fig. 6.11 consists not only of people who work for Sonera, but also of external experts.

Borders of Sonera organization

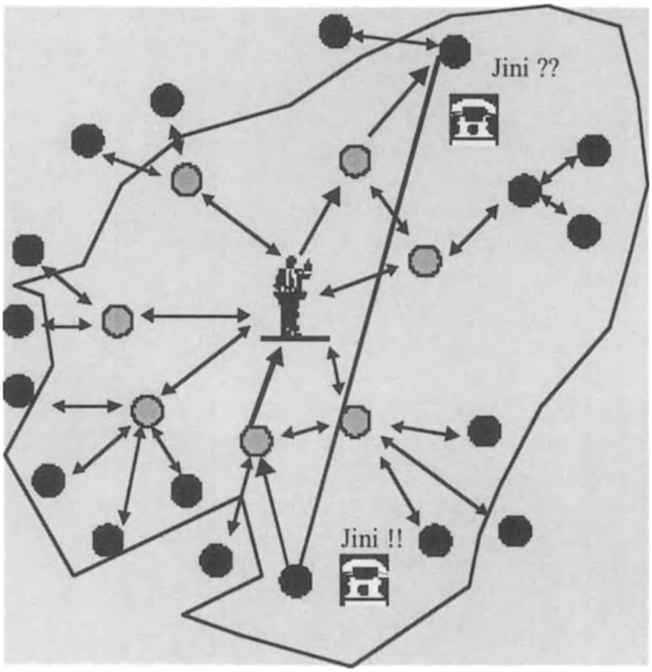


Figure 6.11. The TI-network in Sonera (Adopted from Kulha 2002).[a]

[a]Kulha, Tero 2002. Technology Intelligence, Haasteita ja käytäntöjä. 14.5.2002 Viva Business Intelligence seminar.

A part of the strategy process, which Sonera is going through quarterly, is to build different scenarios about the future state of different technologies. The information, which is collected and summarized by the agents, is used in this strategy process and for working with different scenarios.

Best practices from Sonera in building a TI-organization

There are five best practice insights when building a TI network:

- *One hundred percent TI manager*: it is essential to have one full-time person taking care of technology intelligence. Another option is to have two part-time persons, but without proper resources the network won't survive and bring any benefits.

- *Expand the network outside the company*: the network should cover also persons working outside the company. This happens normally through personal relations of the agents.

- *Create a common technology comprehension*: the technologies followed should be understood in the same way, so that not too much energy would go into finding out and streamlining the information collected
- *Combine TI with other intelligence.* TI should be combined with other intelligence, meaning that the TI function shouldn't be treated as a separate entity but as a part of the whole intelligence function of the company
- *Concentrate on 2nd and 3rd level horizons*: the focus of the TI function should be in the 2nd and 3rd level, where the second level represents mature technologies and the third level technologies which might be reality with a longer perspective.

Of course there are challenges with the TI network as well. The challenges found in the case of Sonera were as follows:

- How to get the information before it is already in the media
- How to create superior knowledge from data that is available to everyone
- The flood of information → how to find ways for smart filtering
- The role of weak signals → how to accumulate them
- Tools for an analysis of the long term technological trends
- Tools for ad-hoc analysis for urgent cases

To summarize this case and the lessons learned from it, there are three key observations. First of all, the TI works and gives good results. Secondly, the different intelligence views applied should be combined through cross-functional discussions in order to provide the best possible results. Thirdly, there must be a process in place to really take advantage of the TI network - otherwise the reports will end up in the archives.

7.10.5 Knowledge Portal

The Case of Cisco[7]

Cisco Systems is a large corporation that manufactures network infrastructure equipment. At a certain point in time the aim was to grow

[7]Full description of the case is available in ASTD's magazine, All about e-learning: http://www.learningcircuits.org/2002/may2002/schneble.html

the size of the new Service and Support Advocacy group, from 20 to 120 people. As the leading supplier of high-performance internetworking products, Cisco provides most of the infrastructure for the Internet.

With more than 40,000 employees and a record growth, the need for quick and easy access to information is vital to Cisco. Cisco runs a significant amount of its internal operations on its corporate intranet, which is critical to customer support.

Objectives

With the goal of hiring 250 service and support managers in a period of 18 months, Cisco needed a comprehensive knowledge management solution that provided the new group with immediate access to crucial resources as well as orientation and reference information.

A fast access to this information would help reduce the time to proficiency in Cisco's fast-paced work environment. Cisco also needed to leverage the expertise of its experienced employees by capturing and sharing their knowledge. The objectives of the project can be summarized as follows:

1 to provide information specific to the service support manager role, such as best practices of how other service support managers handled certain customer situations, goal setting, and advice on when and how to engage other departments within Cisco;

2 in Cisco's geographically dispersed work environment, to develop a communication vehicle for sharing information and experiences with other team members.

Solution

Cisco implemented the Integrated Knowledge Architecture (IKA) from VisionCor. IKA is an object-oriented approach to organizing content based on how the content is used. IKA also provides a guide for organizing information and learning, and for sorting knowledge into smaller pieces called knowledge objects and then building meaningful relationships between those objects.

The end-user can locate the critical information needed to improve productivity and performance more quickly and easily. IKA is technology-neutral and can be used to leverage the capabilities of most major portal or knowledge management platforms.

The high-level steps of the IKA methodology are as follows:

- define the site's purpose

- define the site's content
- classify and organize the content
- identify and develop knowledge objects
- define the site's organizational and navigational schemes
- create a site maintenance plan
- create and rapidly deploy a prototype
- validate the site design by conducting a usability test
- make necessary changes based on the usability test
- continue to maintain, cultivate, and migrate knowledge
- conduct periodic value-add measurements to ensure continued effectiveness

Through interviews with existing managers, the team of consultants gathered, analyzed, and organized the events and tasks required for a new manager. The project sponsor and business managers helped select the best people to interview. A mix of new hires and experienced managers were consulted to determine the most useful and valuable information to include.

To minimize the burden on people to contribute to the knowledge portal, interviewers maintained a reporter-type position to solicit content and to ensure consistent writing and formatting, which varied based on the content type.

In the second phase the consultants conducted additional interviews to help build consensus within the company on some of the aspects of the support manager role.

With a consensus in place they built an overall site map and a detailed content plan. The site look and feel was designed around content, audience analysis, and the existing intranet. Information was then converted into a Web format.

The site navigation, graphics, and initial content were developed; usability tests were conducted to ensure that the site structure was intuitive and the content was meaningful.

Next, developers began integrating content so that the navigation was intuitive, which required a thorough understanding of the users and how they would use the portal.

After that the knowledge portal was retested. Users were given varied scenarios or situations and asked to use the Website to find the information they needed to best respond to the situation. Developers conducted analysis based on how managers used/didn't use – the portal.

In addition to providing feedback, the usability tests also assisted in user acceptance of the site, which is crucial for any knowledge management initiative. Because the portal is a growing collection of knowledge and experience, ongoing development continues through periodic reviews and additions to the Website.

The results

Cisco's service and support advocacy intranet site was very well received within the organization. Currently, Cisco is working with the IKA methodology to leverage the knowledge and benefits gained from the project into other areas of their organization.

References

[1] Avison, D, Lau, F., Neilsen, P.A. and Myers, M. (1999), "Action research", Communications of the ACM, Vol. 42, No. 1, pp. 94-97.

[2] l'Association Européenne pour l'Administration de la Recherche Industrielle, 1999. The management of corporate knowledge. Summary of EIRMA working group 54 report, http://www.eirma.asso.fr/pubs/abstract54.pdf

[3] Baird, L. and Henderson J.C. (2001), The knowledge engine. How to create fast cycles of knowledge-to-performance and performance-to-knowledge. BK Publishers

[4] Bargal, D., Gold, M., and Lewin, M. (1992), Introduction: The Heritage of Kurt Lewin. Journal of Social Issues, Vol. 48, 2. pp. 3-13.

[5] Baskerville, R. and Wood-Harper, A.T. (1996), "A critical perspective on action research as a method for information systems research", Journal of Information Technology, Vol.11, No.3, 235-246.

[6] Bayer, J. and Harter, R. (1991), "Miner", "Manager" and "Researcher": Three Models of Analysis of Scanner Data, International Journal of Research in Marketing, Vol 8, 1991, pp 17-27

[7] Beckman, T.J. (1999), The Current State of Knowledge management, in Liebowitz, 1999"Knowledge management handbook", 1999, CRC Press

[8] Brooking, A. (1996), Intellectual capital: core assets for the third millennium enterprise. London: Thomson business press.

[9] Brynjolfsson, E. (1998), "Beyond the Productivity Paradox: Computers are Catalysts for Bigger Changes", Communication of ACM, Vol. 41, No. 8 pp. 49-55, August 1998.

[10] Carlsson, C. and Fullér, R. (1995), Active DSS and Approximate Reasoning, Proceedings of the EUFIT'95 Conference, Verlag Mainz, Aachen 1995, pp 1209-1215

[11] Carlsson, C. and Fullér, R. (2002), Project Scheduling with Fuzzy Real Options, in Trappl (ed): Cybernetics and Systems'2002, Vienna 2002

[12] Checkland, P. (1981), Systems Thinking Systems Practice.

[13] Checkland, P., Holwell, S. (1998), "Information, Systems and Information Systems - making sense of the field", John Willey & Sons.

[14] Chan, Y. (2000), "IT Value: The Great Divide Between Qualitative and Quantitative and Individual and Organizational Measures", Journal of Management Information Systems, Vol. 16, No. 4, Spring 2000, pp. 225-261.

[15] Cody, David (2001), Incorporating KM into Ogilvy Mather. Knowledgeboard 1st June 2001. www.knowledgeboard.com

[16] Coff, R. W. and Laverty, K. J. (2001), Real Options on Knowledge Assets: Panacea or Pandora's Box?, Business Horizons, Nov/Dec2001, Vol. 44 Issue 6, pp.73-80

[17] Daft, R.L. and K.E.Weick, Towards a Model of Organizations as Interpretation Systems, Academy of Management Review, Vol 9, No.2, pp 284-295, 1984

[18] Durand, T.E., Mounoud, E. and B. Ramanantsoa, Uncovering Strategic Assumptions: Understanding Managers' Ability to Build Representations, European Management Journal, Vol 14, No.14, August 1996, pp 389-397

[19] Dutton, J.E. and S.E.Jackson, Categorizing Strategic Issues: Links to organizational Action, Academy of Management Review, Vol 12, No.1, pp 76-90, 1987.

[20] Davenenport, T., Delong, D and Beers, M. (1997), "Building Successful Knowledge Management Projects". June 6 1997, Working Paper, Ernst & Young Center for Business Innovation. (also published in Sloan Management Review, Winter 1998).

[21] Davenport, Thomas H. & Grover, V. (2001), Knowledge Management. Journal of Management Information Systems, vol 18, No. 1, Summer 2001.

[22] Davenport, T. and Prusak, L. (1998), "Working knowledge". 1998.

[23] Dubois, D., Lang, J. and Prade, H., (1992), "Inconsistency in possibilistic knowledge bases: to live with it or not live with it", in L. Zadeh and J. Kacprzyk (eds.): Fuzzy Logic for the Management of Uncertainty, Wiley-Interscience, New York 1992, pp 335-352

[24] Earl, M. (2001), "Knowledge Management Strategies: Toward a Taxonomy", Journal of Management Information Systems, Vol. 18, No. 1, pp. 215-233.

[25] Eden, C. (1990), Strategic Thinking with Computers, Long Range Planning, Vol 23, No.6, 1990, pp 35-43

[26] Edvinsson, L. and Malone, M.S., (1997), "Intellectual Capital: Realizing Your Company's True Value by Finding Its Hidden Brainpower " Harper Business 1997

[27] Hamel, G. and Prahalad C.K., (1996), Competing for the Future, Harvard Business School Press, Boston 1996.

[28] Hansen, M., Nohria, N. and Tierney, T. (1999), "What's your strategy for managing knowledge?", Harvard Business Review, Vol 77, No. 2 , 1999, p.106

[29] Gioia, D.A. and Chittipeddi, K. (1991), Sensemaking and Sensegiving in Strategic Change Initiation, SMJ, 12 (6), pp 433-488, 1991

[30] Iivari, J., Hirscheim, R., and Klein, H., (1998), A Paradigmatic Analysis Contrasting Information System Development Approaches and Methodologies, Information Systems Research, Vol. 9, No.2, June 1998, pp.164-193.

[31] Jackson, S. and Dutton, J.E. (1988), Discerning Threats and Opportunities, Administrative Science Quarterly, 33 (1988), pp 370-387

[32] Jennings, Nicholas R. and Michael J. Wooldridge (eds), Agent Technology. Foundations, Applications and Markets, Springer-Verlag, Berlin 1998

[33] Kakihara, M. & Sørensen, C. (2001), Exploring Knowledge Emergence. In Managing Knowledge: Controvercies and Critiques. International Conference, 10-11 April, Leicester University, UK, ed. C. Carter, H. Scarbrough, and J. Swan.

[34] Kaplan, R.S. and Norton, D.P. (1996), Balanced Scorecards: Translating Strategy into Action, Harvard Business press.

[35] Kelleher, PriceWaterhouseCoopers, (2002), Towards Common approaches and Standards in Knowledge Management, Seminar Report, accessed at http://www.knowledgeboard.com/cgi-bin/item.cgi?id=84481 on 30.08.2002. KPMG Knowledge Management Research Report, 2000, KPMG Consulting.

[36] Lau, F. (1997), "A review on the use of action research in information systems studies",

[37] Lee, A., Liebenau, J. and DeGross, J. (1999), Information Systems and Qualitative Research, Chapman & Hall, London, pp. 31-68.

[38] Liebowitz, J. (Ed.) (1999), "Knowledge management handbook" 1999.

[39] Markus, M. Lynne (2001), Toward a Theory of Knowledge Reuse: Types of Knowledge Reuse Situations and Factors in Reuse Success. Knowledge

[40] Management, Journal of Management Information Systems, vol 18, Number 1, Summer 2001.

[41] Markus, M.L., Majchrzak, A. and Gasser, L. (2002), A Design Theory for Systems that Support Emergent Knowledge Processes. MIS Quarterly, Vol. 26. No.3, pp. 179-213, September 2002.

[42] McKay, J. and Marshall, P. (2001), "The dual imperatives of action research", Information Technology & People, Vol. 14 No. 1, pp. 46-59

[43] Mintzberg, H. (1989), Mintzberg on Management, Free Press, New York 1989

[44] Nemati, H.R., Steiger, D.M., Iyer, L.S., Hershel, R.T. (2002), "Knowledge warehouse: an architectural integration of knowledge management, decision support, artificial intelligence and data warehousing" in DSS Journal, Vol 33 (2002) pp 143-161

[45] Neubauer, F.F. and Solomon N.B. (1977), A Managerial Approach to Environmental Assessment, LRP, Vol 10, April 1977, pp 13-20

[46] Nonaka,I. and Takeuchi, H. (1995), The Knowledge-Creating Company: How Japanese Companies Create the Dynamics of Innovation, Oxford University Press, 1995

[47] Polanyi, M. (1967), The Tacit Dimension, London, UK: Routledge & Kegan Paul.

[48] Roos, R., Roos, J., Edvinsson, l. and Dragonetti, N.C. (1997), Intellectual Capital - Navigating in the New Business Landscape.

[49] Ruggles, R. (1997), Knowledge Management Tools, Butterworth-Heinemann, Boston, MA.

[50] Schneider, S.C. and Meyer A.D. (1991), Interpreting and Responding to Strategic Issues: The Impact of National Culture, Strategic Management Journal, Vol 12, pp 307-322, 1991

[51] Simon, H. A. (1981), The Sciences of the Artificial. (2nd edition). Cambridge, MA: MIT Press.

[52] Skyrme, J. and Amidon, D. M. (1997), Creating the Knowledge-based Business, Business Intelligence, London.

[53] Stewart, T. (2002), The Wealth of Knowledge: Intellectual Capital and the 21st Century Organization," to be published in January, Currency Doubleday.

[54] Strassmann, P.A. (1999a), "The Search for productivity", Computerworld, August 09, 1999.

[55] Strassmann, P.A. (1999b), "What's the key to implementing knowledge management?", Knowledge Management Magazine, April 1999.

[56] Strassman, P. (2000), "Intelligence in Question" Knowledge Management Magazine, October 2000.

[57] Varela, F., E. Thompson, & Rosch, E. (1991), The Embodied Mind: Cognitive Science and Human Experience. Cambridge, MA: MIT Press.

[58] Weick, K.E. (1995), Sensmaking in Organizations. London: Sage Publications.

[59] Winograd, T. & F. Flores (1986): Understanding Computers and Cognition: A New Foundation for Design. Norwood, NJ: Ablex Publishing.

[60] Yager, Ronald R., Sergei Ovchinnikov, Richard M.. Tong and H.T. Nguen (eds.), Fuzzy Sets and Applications: Selected Papers by L.A.Zadeh, J Wiley & Sons, New York 1987.

[61] Zack, M. (1999), Managing Codified Knowledge, *Sloan Management Review, Summer*, 45-58.

[62] Zadeh, Lotfi A. (1965), Fuzzy Sets, *Information and Control*, Vol 8, 1965, pp 338-353.

[63] Zadeh, Lotfi A. (1973), Outline of a New Approach to the Analysis of Complex Systems and Decision Processes, *IEEE Transactions on Systems, Man and Cybernetics*, Vol 3, 1973, pp 28-44.

[64] Zeleny, M. (1987), Management support systems: towards integrated knowledge management", *Human Systems Management*, 7(1987) 59-70.

Chapter 7

MOBILE TECHNOLOGY APPLICATIONS

1. Introduction

We have chosen a European perspective for our study of mobile technology applications. There are several reasons for this. The growth in GSM acceptance has been extremely fast, the penetration of mobile phones reached 63% in 2000, which translates to eleven times the number of users in 1995 and a total of 252 million users (cf. the Durlacher UMTS Report). This is a fast growing potential, large and very significant market for products and services which use the GSM standard mobile platforms. This market has continued to grow at a rapid pace despite some slowdown in 2002-2003 due to the slowdowns and recessions in some key EU economies.

The Durlacher UMTS Report works with a scenario that expects mobile voice communication to reach a saturation level of 87% around 2005-6, as this year (2003) about 75% of the European population will be using mobile phones (more than 300 million users). The saturation of mobile voice demand will shift the focus to mobile data communication and this is where we get the drivers for m-commerce products and services. The Durlacher study notes that the investment in UMTS licences throughout Europe reached - 120 billion but makes the optimistic proposal that this will not slow down investments in the new mobile technology, which are estimated to reach - 260 billion, because the initial licence costs will be worked in to the business models by 2005 and largely forgotten as they are being covered by growing streams of revenues. This will put a viable infrastructure in place for the data communication, which will grow to 350 million connections by 2005 running more than 3000 applications.

The technologies and the markets grow in tandem, and it is important to realise that the development of the mobile markets will be evolutionary, i.e. new products and services will have a backbone and a basis in the existing products and services. We cannot expect to stumble upon revolutionary new (killer) applications that will happen overnight with the introduction of the UMTS networks (even if this actually could happen). There were a number of first applications, which were introduced in the GSM networks and discarded because they were slow and cumbersome, which have now reappeared in the GPRS networks and are gaining acceptance. The WAP was a failure in the GSM but is gaining increasing acceptance in the GPRS, and news, information and entertainment services, which are built as WAP applications, are getting more and more acceptance. Common wisdom had it that the WAP will be replaced by the Japanese i-Mode but the introduction of this standard has been very slow in UK, Germany and The Netherlands and will probably not become an alternative to WAP, GPRS and UMTS.

Another common wisdom is that multimedia services will drive the acceptance of the new mobile technology and speculations are growing on what people would want to do with advanced multimedia. The facts of technology do not support this - the GPRS networks cannot handle more than very limited video applications and the early UMTS networks will not provide the envisioned 2 mbps capacity, which will be reached only around 2008-2009 (if we talk about a European-wide use, there will of course be regional exceptions). Then it is interesting to note the visions voiced by senior representatives of the major mobile hardware vendors. In a survey published in the Finnish daily Helsingin Sanomat on March 23, 2003 senior executives of Nokia Mobile Phones, Motorola, Samsung, Siemens and Sony Ericsson were asked when they believe that the penetration of 3G services and applications have taken place - all of them agreed that this has happened by 2006. The response on the question where the most attractive 3G services are to be found varied quite interestingly:

Nokia: multiple services can be used simultaneously; most services emerge through evolution

Motorola: those services which are more useful, more valuable and more fun if they can be used spontaneously, i.e. through wireless

Samsung: multimedia, mobile commerc e and localisation-using services

Siemens: multimedia, entertainment, payment and localisation-using services

Sony Ericsson: video conferencing

Another interesting set of facts can be found in the TNS Telecoms 3G 2003 report (cf. MobileInfo, February 2003), which was carried out in 10 EU countries. It was found that 42% of European mobile phone users are interested in 3G services. An interesting observation was that a majority of the users were prepared to pay extra for 3G hand- sets and services. The average monthly invoice for a mobile phone user in Europe is currently 26 - (20 - for prepaid and 37 - for contracts). An interesting 50% of those interested in 3G services were willing to pay an additional 6-10 - per month for 3G services such as MMS, high speed internet and email. A majority of respondents across all countries surveyed were willing to pay up to 330 - for a 3G handset. The most favoured 3G applications were (i) sending and receiving email on mobile phones (77%), and (ii) using videophone handsets (77%), but the least favoured applications were, (iii) downloading music files (47%), and (iv) the viewing of video clips (40%).

These are visions and speculations, but the message the studies convey supports the evolutionary, gradual development of mobile services - the users will work with applications they can incorporate in their everyday activities and then they change to more advanced services as these become feasible and useful. It appears to be the exception that users jump to a service just because it has become technically available.

These fragmentary and quick sketches will serve as a background for working with the mobile commerce (m-commerce), which we will use both as a research area of conceptual constructs and theory formation and as a domain for empirical studies. Mobile commerce is where mobile technology applications become practical and start generating an understanding among everyday users of the technology. It suffered from an early wave of hype and the hunt for "killer applications" in 1999-2001, but there is now a more realistic discussion of its possibilities.

The work with value propositions should start from some simple observations, which are at the core of the applications built around the mobile, wireless technology:

- *Mobility*, mobile phones are brought along as individual tools and instruments, which has changed the everyday routines of communicating significantly
- *Availability*, mobile phones allow their users to be continuously connected, which has changed the communication infrastructure in significant ways
- *Ubiquity*, network interconnectivity and roaming agreements allow mobile communication anywhere and at any time

We will state as a proposal that any m-commerce service should show an evolutionary path of development from these three value-building features.

The conceptual discussion of m-commerce starts, in most of the cases, from the conceptual constructs of e-commerce. It is probably only a coincidence but e-commerce has not yet reached the explosive growth figures which were commonly predicted in the mid-1990s, and turned out to be as unrealistic as the early predictions of explosive growth figures for m-commerce in the foresight scenarios of 1999-2000. Partly as a consequence, scholars and industry representatives are turning their attention to the promise of electronic wireless media, envisaging that the next - or the real phase of e-commerce growth - will be in the area of mobile commerce (see e.g. Hampe et al., 2000; Varshney et al., 2000; Kalakota and Robinson, 2001; Varshney and Vetter, 2001; Li, 2002).

Keen and Mackintosh (2001) defined m-commerce as the extension of electronic commerce from wired to wireless computers and telecommunications, and from fixed locations to anytime, anywhere, and anyone. On the other hand, mobility in itself and mobile technology is not necessarily a value, but the *freedom* created and supported with the technology is the key issue. Freedom, Keen and Mackintosh say, makes a real difference to how m-commerce customers go about their day, to how companies build their options and design new business processes and how their staff mobilizes the organization's knowledge and communication resources.

Freedom is about choices and value for customers and consumers. The choice has to translate to values that customers are willing to pay for and that companies can afford to provide. The very core of the m-commerce is to make the user the centre of the information and communication world in relationships and business operations that create new freedoms for the user.

May (2001) found that when something is mobile it means that its primary usage environment is a mobile one, but he goes on to define m-commerce as "electronic commerce using mobile devices such as cell phones as client devices". Paavilainen (2001) takes issue with this notion. He defines mobile business as "the exchange of goods, services and information using mobile technology " and notes that mobile business is a broad definition that includes communication, transactions and different value added services using various kinds of mobile terminals. Then he goes on to define mobile commerce as "transactions with monetary value, conducted using the mobile internet", which he recognizes to cover business-to-business, business-to-consumer and consumer-to-consumer transactions.

Traditional voice calls are not included in m-commerce but services using voice recognition to enable commercial transactions fall into this category. Paavilainen points out that the term "mobile e-commerce" is misleading because the business models and the value chain are totally different from electronic commerce. We agree, based on our empirical studies, that (cf. p 2) "mobile commerce is not a truncated form of e-commerce but a new, innovative way of conducting time-critical transactions regardless of location". Kalakota and Robinson (2001) place themselves somewhere in between May and Paavilainen with the notion that m-commerce is an evolution of the e-commerce paradigm from fixed networks to wireless data networks. They also recognize that mobile commerce refers to business transactions conducted while on the move and they expect the growth in m-commerce to be driven by users seeking to conduct business, communicate and share informa- tion while away from their fixed network connections. Kalakota and Robinson (2001), however, do not recognize that the paradigm evolution actually is a paradigm shift from e-commerce to m-commerce.

Kalakota and Robinson (2001) make the point that m-commerce is not about telecom infrastructure, operating systems and software breakthroughs but about applications and solutions for everyday users in various contexts and locations. Nevertheless, it is helpful to recognize that m-commerce products and services are information systems constructs (software) (Carlsson 2002, Carlsson and Walden 2001-2002) and that the features referred to in the various definitions can be implemented as software designs.

Bearing this in mind it is possible to work out the designs of m-commerce products and services in terms of software modules, layers of software components and bundles of modules, which make the features to be built for various categories of users in a variety of contexts as useful and as freedom-building as possible.

Although the mobile Internet appears to have much to offer as an instrument of commerce, little is known about the consumers' willingness to adopt wireless electronic media, and the factors that influence their adoption decisions and value perceptions of the products and services which form m-commerce (cf. Urbaczewski et al,. 2002; Pedersen et al., 2002). We are now gradually starting to understand the unique characteristics of the fixed Internet, but the wireless Internet raises many of the same questions in a new context (Gurley, 2000; May, 2001). Building successful strategies for the mobile marketplace begins with a recognition of the distinctive forces which drive the emergence of m-commerce (Senn, 2000): on the Internet, firms can create value for customers in a manner that is different from that which has been achieved in conventional business (Han and Han, 2001).

Correspondingly, m-commerce is expected to possess unique characteristics in relation to e-commerce, and many statements on an impending m-revolution have been triggered by the assumption that the potential of m-commerce will involve (i) lower barriers, and (ii) greater benefits in comparison to both fixed e-commerce and traditional commerce.

In view of that, the key question for m-commerce is to find some way to assess the value of mobile applications to prospective users (Carlsson and Walden, 2002), and to gain an understanding of the factors that may delay the penetration of the mobile Internet on a larger scale (Lee et al., 2002). Such insights are certainly needed to form the foundations for conceptual frameworks, systematic research and an effective research methodology, but also to support investment decisions, to find viable business models and to develop mobile devices, networks, and services that address and take the concerns/wants of consumers into consideration.

Conceptual frameworks and a background in theory are all quite in order, but we need some facts as a basis in order to make them work and to get a good understanding of the issues involved.

2. Consumer Survey in Finland

The purpose of the study was to solicit information from Finnish consumers about the kind of mobile devices they are using, and their perceptions and attitudes towards current and future use of mobile products and services[1].

We conducted a sample survey and the sampling design was based on the structure of the population in mainland Finland with some specifications according to the following population characteristics: age, mother tongue and household location. The required sample size was determined to 1000. A random sample was drawn by the population register centre, which collects official information for the whole country on Finnish citizens and aliens residing permanently in Finland.

In designing the questionnaire we checked both the content, layout and appearance before the questionnaire was ready for pre-testing, after which we made some changes before the final draft of the questionnaire was ready. In the questionnaire we used mainly structured questions. In order to make the questions understandable for the respondents we presented examples from the everyday life.

The data were collected with a mail questionnaire. A prize competition was arranged among the respondents in order to improve the rate of responses given. The mailing was conducted in March 2002, and two reminders were sent to the respondents in April. The percentage of re-

[1]An early version of this material was published in the ECIS 2002 Proceedings.

sponses was 49.9% out of which we were able to accept 48.7%, i.e. 487 responses. Background data The respondents were categorized in the following age groups, 16-22, 23-35, 36-50, and 51-64. The four groups are expected to differ from each other with respect to usage, perception and attitudes. Besides that we also expect differences based on gender.

Accessing internet by computer and mobile device

The majority of the respondents had used internet via a computer (81.8%) but via a mobile device less than a sixth (15.9%). The majority of the respondents seemed to be familiar with using a computer (75.1%). The biggest group of nonusers are in the age category 51-64 where 37.3% had not accessed internet via a computer. Purchasing via a computer was not unusual (34.8%), still purchasing via a mobile device was extremely unusual (4.4%).

Mobile Devices in use

Most people in Finland have a mobile device and 88.9% of the respondents use a mobile device. The great majority have a GSM device (77%) and some have several devices in use (7.8%). Only a few respondents had a communicator (0.8%), a GPRS- (0.6%) or a WAP-enabled phone (2.7%). Only 11.1% of the respondents said that they did not use a mobile device. As the share of nonusers and those who use a GSM- phone is 88.1 % no further analysis is meaningful relative to the available devices of the respondents (in the following "mobile phone" as this clearly is the most widely used mobile device). The mobile phones are used only or mainly for personal use by 72.8% and only or mainly for business use by 11.5%, the rest is divided equally between personal and business use (15.6%).

More than half of the respondents (63.6%) declared that they will change their mobile phone within the near future. Almost all of those phones will be changed for a new phone within two years and 56.6% will change their mobile phone within one year. Most of the respondents were planning to change their phones to a new GSM phone (50.2%). A rather big group (24.7%) did not know to what kind of mobile phone they would choose. GPRS was found attractive by 9% and a communicator by 4.5%. Only 4.1% said that they would change to a mobile phone with a colour display. There were no statistical differences between male and female respondents and between the different age categories.

Who is paying for the usage of the mobile phone?

Most of the respondents said that they are paying for their own mobile phone usage (69.7), and only a few (12.5%) said that their employer is paying for the usage. Not too many (9.7%) were having a family member to pay for the use of the mobile phone. Taking care of the bills jointly with someone else was also a possibility (11.1%).

Benefits and barriers of mobile services

Using a five point Likert scale we asked the respondents to indicate their degree of agreement or disagreement with benefits and barriers associated with the use of mobile services. We analysed the data on an item-by-item basis (figure 1 and 2). There are not too many differences between the opinions in the different age categories; flexibility in using the mobile services anywhere and anytime is seen by all as a benefit as well as enhancing communication, convenience and handiness. The younger respondents (age categories 16 to 22 and 23 to 35) have a more positive opinion than the older respondents.

We were looking for differences according to gender. Flexibility in using mobile services is valued by women (chi-square 12.1 Sig. 0.002). The majority of the respondents do not see being trendy/up to date when using a mobile service as a benefit, but when we look at the gender we find a statistical difference (chi-square 12 Sig. 0.002) as those who see it as a benefit are mainly women. Enhancing the social status shows as well a statistical difference in gender (chi-square 8.5 Sig. 0.014). Also here those who see it as a benefit are women.

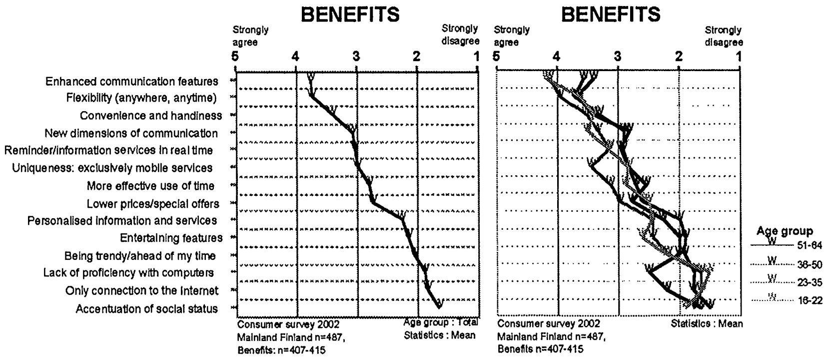


Figure 7.1. Mobile services - benefits.

When we consider the barriers associated with the use of mobile services the profiles for the age categories differ. The profiles for the age categories 16-22 and 23-35 show rather similar patterns and the profiles for the age categories 36-50 and 51-64 show similar patterns. High initial and operating costs, limited capacity of the mobile devices, slow data connections as well as the small screen size of the mobile devices are seen as major barriers in all categories but with different magnitude. The complexity of using the mobile devices is a barrier for the respondents in the older age categories. Respondents in the younger age categories are not as concerned about privacy and security issues as are those in the older age categories.

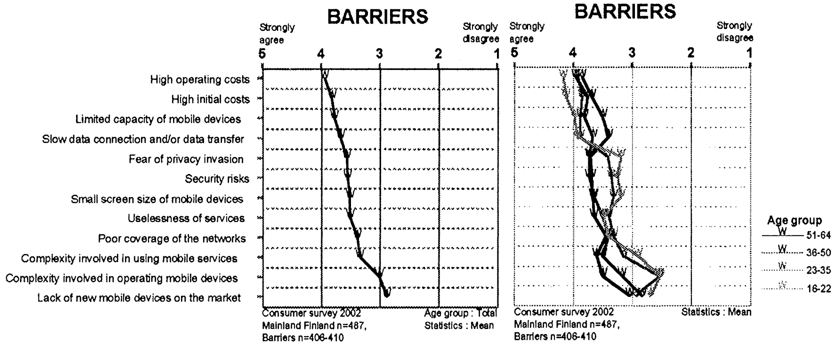


Figure 7.2. Mobile services - barriers.

We found some statistical differences in gender. High initial costs are a barrier for women for using mobile services (chi-square 12.4 Sig. 0.002). Slow data connections are a barrier for men (chi-square 9.5 Sig. 0.008). Male respondents consider the use- lessness of mobile services as a barrier (chi-square 6.18 Sig. 0.045). Mobile services in use now and in the future There are several mobile services available on the Finnish market. We specified 25 different mobile services in the questionnaire. We asked the consumers if they use these services today

and if not, would they be interested in using them in the future. We will discuss some of the services which have rather a big share of users among the respondents and some which are often mentioned in connection with mobile services (Table 7.1).

SMS

Almost all of the consumers use SMS. The distribution between male and female is significantly different (chi-square 5.6 sig. 0.018 (asymp.sig., 2-sided)). There are more female consumers who use SMS than there are male users. If we compare the results according to the age categories we find significant differences between male and female aged 51-64 (chi-square 7.8 sig. 0.005 (asymp.sig., 2-sided)).

Female consumers in this category are the typical SMS users. In general we can say that a typical SMS user is a woman. Of those who are not using the service today, there is only one male respondent in

Table 7.1. Mobile services: distribution between users and nonusers.

Users/non users	yes	no
SMS	375 / 90.1%	41 / 9.9%
Ring tones and icons	215 / 52.3%	196 / 47.7%
Entertainment, games	98 / 23.8%	314 / 76.2%
Routine m-banking	77 / 18.7%	335 / 81.3%
M-email	49 / 11.8%	365 / 88.2%
Personalised information messaging	48 / 11.6%	365 / 88.4%
Ticket reservation	39 / 9.5%	371 / 90.5%
M-payment	31 / 7.5%	381 / 92.5%
Lottery	15 / 3.6%	397 / 96.4%

the age category 23-35 who does not know if he will use the service in the future, the rest are older and most of them will not use SMS in the future.

In the age group 51-64 there is a significant difference between the male and female respondents. The male respondents will not use SMS services in the future.

Ring-tones and Icons

Ring tones and icons are popular m-services in Finland. Half of the respondents use these services. There is no significant difference between male and female users. In the age category 51-64 we found significant differences between male and female users.

Two thirds of those who said they use the services are women. Most of the respondents who do not use the service today are within the age categories 36-50 and 51-64, and the majority definitely or probably not use the services in the future. We did not find any significant differences between male and female respondents' opinions of usage.

Mobile entertainment services: Games

There is no significant difference between male and female users of mobile entertainment services and no differences when we study the age categories. The majority of those who do not use entertainment services will definitely or probably not use them in the future. There is no significant difference between gender or age categories.

Routine mobile banking

There is no significant difference between male and female users of routine banking services. There is a significant difference between male and female users in the age category 16-22, most of the users are female (chi-square 5.76 sig. 0.016 (asymp.sig., 2-sided)). The majority of the users will definitely or probably continue to use routine mobile banking.

49% of the nonusers will definitely or probably use the service in the future, 20% do not know and 31% will definitely or probably not use the service. There is no significant difference in opinions between male and female respondents in the different age categories.

M-email

There is a significant difference between male and female users of m-email (chi-square 6.4 sig. 0.011 (asymp.sig., 2-sided)). Male users use more m-email than female users. There is a significant difference between male and female users in the age category 23-35, most of the users are male (chi-square 8.03 sig. 0.005 (asymp.sig., 2-sided)).

Those respondents who are not using m-email, 42.8% of them will definitely or probably use it in the future, 26.6% do not know and 30.6% will definitely or probably not use it in the future. No significant differences were found in gender or age categories.

Personalised information messaging

There is no significant difference between the male and female users of personalised information messaging. There is a significant difference between male and female users in the age category 23-35, most of the users are male (chi-square 6.1 sig. 0.013 (asymp.sig. 2-sided)).

56% of those who do not use personalised information messaging will not use it in the future, 20 % will definitely or probably use it in the future and 24% do not know if they will use it in the future. There is no significant difference in opinion between gender and age categories.

M-ticketing services

There is no significant difference between the male and female users of reservation of movie, concert etc. tickets. Also the age categories do not show any differences in usage.

Those who are not using mobile ticketing services and will definitely or probably not use them in the future are 33.3%, those who do not know are 20.9% and those who will definitely or probably use them are 45.8%. There are no significant differences in age categories or gender.

M-payment

Very few of the respondents had used m-payment and no significant differences are to be found between male and female. There is a difference in the age category 36-50, five men and one women use m-payment. Due to too few observations no definite conclusion can be made.

Among those who are not using mobile payment services, there are differences in gender. In the age categories 16-22, 23-35, and 36-50 there are more women who will definitely or probably not use mobile payment services in the future. In age category 51-64 there are more male that will definitely or probably not use mobile payment services. The differences are however not statistically significant. Those who will definitely or probably use the services in the future are 48%, those who do not know are 24% and those who will definitely or probably not use the services are 28%.

Lottery

Not very many of the respondents use the service but there is a significant difference between male and female users of the mobile lottery service (chi-square 6.2 sig. 0.012 (asymp.sig. 2-sided)). Most of the users of the lottery service are male. Among those who are not using the lottery service today the opinions about future usage is that 46.5% will definitely or probably not use them in the future, 20.7% do not know and 32.8% will definitely or probably use the services.

There are differences among those who will not use the services in the future, the age category 51-64 differs from the rest, there are more male than female in this category and the difference is significant.

In the other three age categories there are more female than men ((chi-square 10.6 sig. 0.014 (asymp.sig. 2-sided)). Among those who do not know about their future usage the difference is in the age category 36-50, the women are those who do not know about their future usage. In the other three categories the male dominate ((chi-square 7.8 sig. 0.05 (asymp.sig. 2-sided)). We did not find any statistical differences in gender or age categories between those who will use the lottery service in the future.

If we compare these results with the predictions given in section 1 by the representatives of Nokia, Motorola, Samsung, Siemens and SonyEricsson we do not find many cases of matching. It may be true that the now existing products and services will develop to the predicted future services through a competitive evolution. Then the challenge will be to understand and predict the steps forming the roadmap.

The consumer survey was preceded by a study of the visions m-commerce experts had of the same market. It is quite interesting to see that the experts are much more positive to the potential of m-commerce applications than the actual users.

3. An Expert Survey in Finland

An expert survey on m-commerce in Finland was carried out in order to get insights into the state, the potential development and the key issues of mobile commerce as they appear in the summer of 2001 (but focused on an outlook for the markets in 2002-2003). A sample of 50 companies was selected out of which 31 participated in the survey. The results are summarized in the following.

The slow speed and the high cost of service, and the limited screen size are seen as the major barriers for a rapid m-commerce expansion. Communication and personalized information applications were rated as potentially successful m-commerce applications. An emerging third group is entertainment applications.

Consumers go wireless because of the high level of flexibility that the mobile devices offer. Other reasons are to improve productivity and to get up-to-date information. Getting personalized information and services were also mentioned as important motivations for customers to use mobile products and services.

The one feasible pricing model seems to be to offer a flat-rate access to m-commerce products and services. The overall acceptance of advertising in the wireless environment is expected to be quite limited. Advertising on request seems to be slightly more attractive than receiving advertisements at regular intervals in order to benefit from discounted rates.

Finnish m-commerce companies seem to be ready to face global competition, but in terms of global market position and customer orientation they are slightly behind their international competitors.

B2C as well as B2B revenues are expected to grow at significant rates in the coming years. Especially the B2B revenues are rising at a faster pace than B2C.

Finland is considered to be the leading country in m-Commerce usage. The Top 3 group also includes Japan and Sweden; China is rated as the least promising country.

E-Commerce revenues in the B2B market and m-Commerce revenues in the B2C market are both predicted to grow strongly by the year 2005.

Most of the Finnish companies participating in the survey have been active in mobile commerce for 12 - 24 months. A small percentage of the respondents are not offering m-commerce products and/or services of any kind. The typical m-commerce offerings were SMS and e-mail, personalized information and entertainment applications. Not surprisingly, these were the same products and services, which were judged to have the best potential for the future.

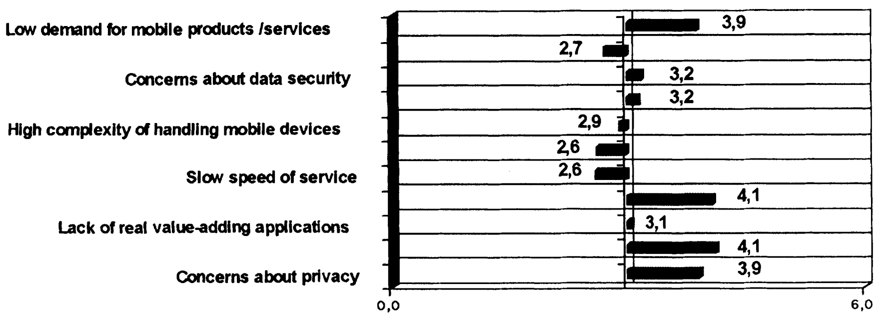
The Finnish companies find the future to be very positive. The revenues generated with mobile commerce products and services are estimated to more than double in the years 2002-2003.

The most frequently proposed "best" applications for the Finnish market were SMS, MMS and mobile e-mail. Entertainment applications, personalization and location based services were also listed among the top 10 products and services.

According to the respondents, personalization, messaging and value adding mobile services are going to be the primary areas of research in the near future.

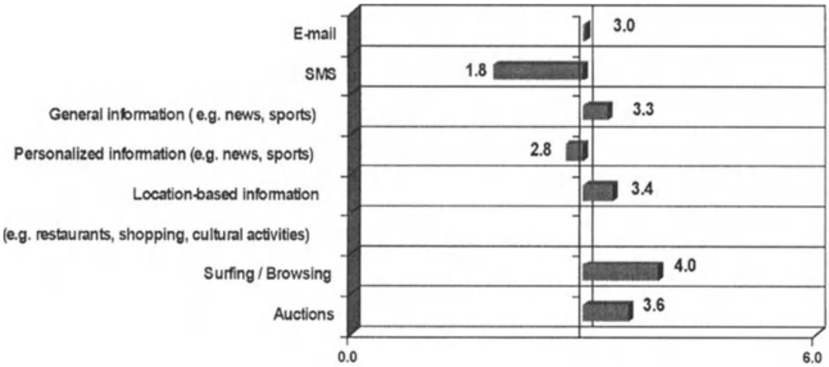
The 50 companies selected for the survey were (i) providers of m-commerce products and services, (ii) providers of m-commerce infrastructure and (iii) providers of consulting and financial services in the area of m-Commerce. The companies were contacted by phone, e-mail and regular mail, but the survey was carried out with a web-based questionnaire. The respondents actually had a choice of filling in the questionnaire while online or printing it out and sending the completed form via regular mail. All the respondents chose to use the electronic form. The time frame for the survey was June-August, 2001. In the following some summary data on details from the survey will be presented.

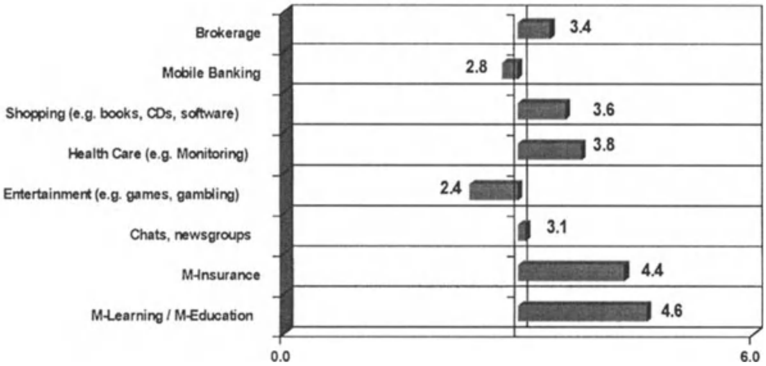
Q1. Which of the following factors constitute a barrier to a rapid expansion of m-Commerce in the next 18 months? [0.0-3.0 = large barrier; 3.1-6.0 = small barrier]



Key results: The slow speed of service is seen as a major barrier for rapid m-Commerce expansion. Also limited screen size of mobile devices and high cost of services are perceived to be inhibitors to prompt mobile commerce diffusion.

Q2. How do you evaluate the likelihood of firms achieving a satisfactory level of turnover for the following m-commerce services? [0.0-3.0 = high likelihood; 3.1-6.0 = low likelihood]

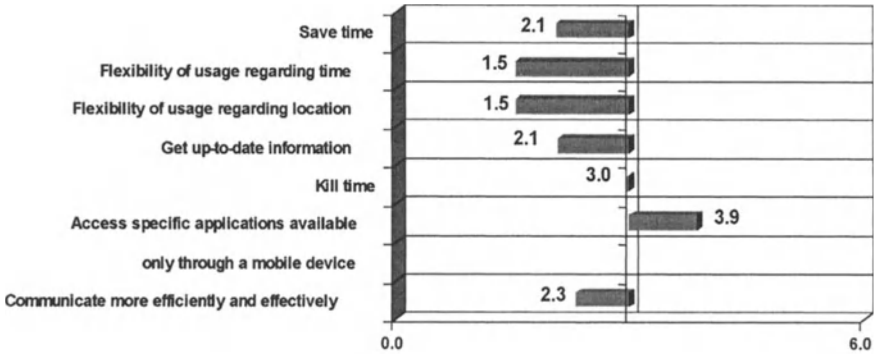


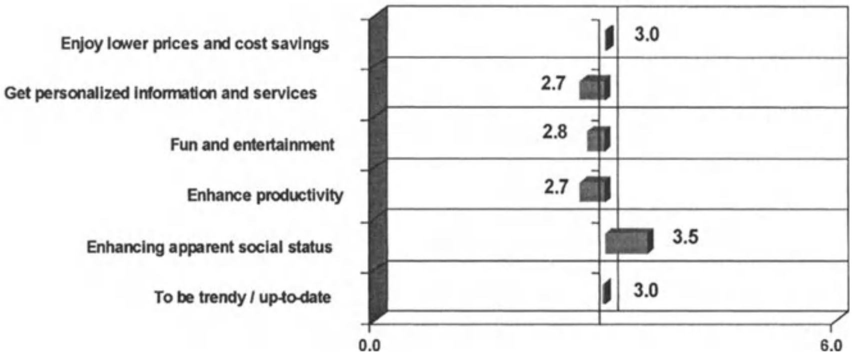


Key results: Communication applications like SMS are supposed to have a high potential of success. Personalized information applications with high value to the customers are also deemed to do well. Other potentially profitable applications are seen especially in the area of entertainment.

Q3. How do you rate the relative importance of the various motivations of both current and future consumers of m-Commerce products / services? [0.0-3.0 = high im- portance; 3.1-6.0 = low importance]

Key results: Consumers go wireless because of the high level of flexibility that the mobile devices offer. Other reasons are to improve productivity and to get up-to-date information. Getting personalized infor-





mation and services is also valued among the experts as an important motivation for customers to use mobile products / services.

The Finnish expert survey was repeated in Hong Kong and Singapore in April 2002[2]. A sample of 50 companies operating in the field of m-commerce was selected in all the countries studied. The Finnish participation was 31 companies (as previously mentioned), in Hong Kong 31, and in Singapore 28. The companies were (i) providers of m-commerce products and services, (ii) providers of m-commerce infrastructures, as well as (iii) providers of consulting and financial services in the area of m-commerce. The survey was carried out using an online questionnaire on the Internet. We measured the experts' opinions mainly using

[2]Doug Vogel, City University of Hong Kong, was responsible for the survey in Hong Kong and Lai-Lai Tung, the Nankiang Technological University, in Singapore.

a forced scale, which requires the respondent to indicate an opinion on the item.

4. Acceptance of Mobile Commerce in Finland, Hong Kong and Singapore

Measuring the general acceptance of m-commerce in Finland, Hong Kong and Singapore is hard especially when the experiences from the three markets are still in their infancy. The experts were asked to evaluate a number of m-commerce services and the likelihood of achieving a satisfactory level of turnover within the next 18 months (Fig, 7.3). When we compare the profiles we notice interesting similarities as well as differences between the expert opinions in the three countries.

The experts' opinions from Singapore and Hong Kong show that mobile shopping is supposed to have a high potential of success. The opinions differ quite a bit when compared with the Finnish experts. The reason for the big gap between the opinions is not obvious and the explanation may be found in some cultural aspects.

The experts' opinions show that communication applications like SMS are supposed to have a high potential of success. There are, however, differences between the expert opinions, the experts in Finland are more positive than their counterparts in Hong Kong and Singapore. As pointed out by Keen and Mackintosh (2001) messaging has been one of the "killer applications" of the Internet, of mobile phones in Europe and Japan, and of a new generation of wireless devices, such as pagers. Mobile messaging for person-to-person communication is for sure an area for services with a high success potential in Finland, but also in Hong Kong and Singapore.

M-learning and m-education are according to the experts in Hong Kong seen as having a good potential for success. The experts in Singapore, and especially in Finland, do not share this view. Again we assume that it might have to do with some cultural differences or is derived from the fact that in these two countries, with about 5 million inhabitants, it wouldn't become a profitable business within the given time frame.

Mobile banking is seen as having a potential for success, especially according to the experts in Hong Kong. Brokerage is also seen to have some potential according to the experts in Hong Kong and Singapore. The Finnish experts are not as positive, which might reflect the fact that the banking markets are not as developed in Finland as in Hong Kong or Singapore.

Other profitable applications, which are expected to be found especially in the area of entertainment, and which is emphasized by the experts in Finland and Hong Kong; the experts in Singapore are less positive in their opinions.

The experts do not think that m-insurance services will turn out to be profitable in the very near future. Traditionally, the insurance business has involved a lot of face-to-face contact due to the complexity of the services and this might be a barrier for the insurance business to go mobile.

If we were to mark anything as a "killer applications" on the Finnish m-commerce market it would certainly be the SMS. A "killer application" on the Hong Kong and Singapore markets would be the possibilities for mobile shopping, which appear to cover only the selection of products and services, not the payments nor the logistics. The differences are still unexplained, and an interesting fact is that "shopping" was emphasized also by the French sample of experts.

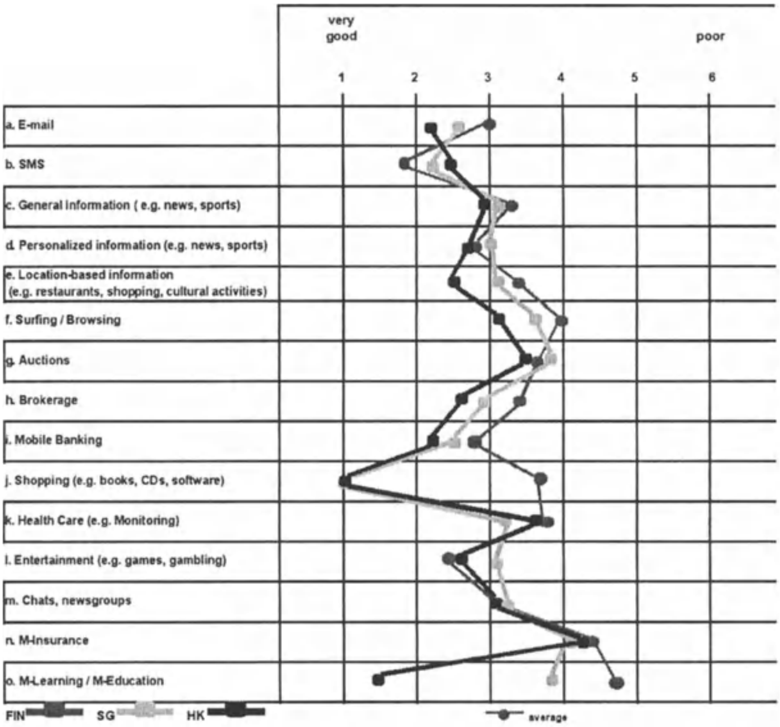
There are differing opinions on "surfing/browsing", which support our earlier discussion of the problems with understanding m-commerce as only an extension of e-commerce. It appears that it may be the case that mobile devices are not seen as good tools for using the Internet, that the surfing and browsing are activities, which belong to workstations and large screens, and to a context where time is reserved for this activity.

Auctions are not seen as a viable activity for the mobile devices, and the reason may again be one of context. Auctions require a focused use of time, which is not a primary expectation for mobile activities.

A bit surprising is that mobile health care is not seen as a key potential activity. The reason is probably that the infrastructure for mobile health applications is still not developed enough.

The relative importance of the various motivations of both current and future customers of m-commerce products and services shows rather slight variations between the experts' opinions in the three countries (Fig. 7.4). The four factors with the highest importance are the same according to the experts. The pair-wise variation between Hong Kong and Singapore is less than when compared to Finland. The results show that the key reasons for using m-commerce technology appear to be (i) flexibility on time and location, (ii) time savings and (iii) to get up-to-date information. When designing m-commerce products and services functionality along these lines should be a first checkpoint. These results are in line with our discussion of the key principles for the mobile world.

Adoption and the use of m-commerce products and services will depend on the attitudes of the individuals. If consumers feel the anytime, anywhere, i.e. the freedom Keen and Mackintosh (2001) are discussing, they will use the products and services. It is obvious that m-commerce



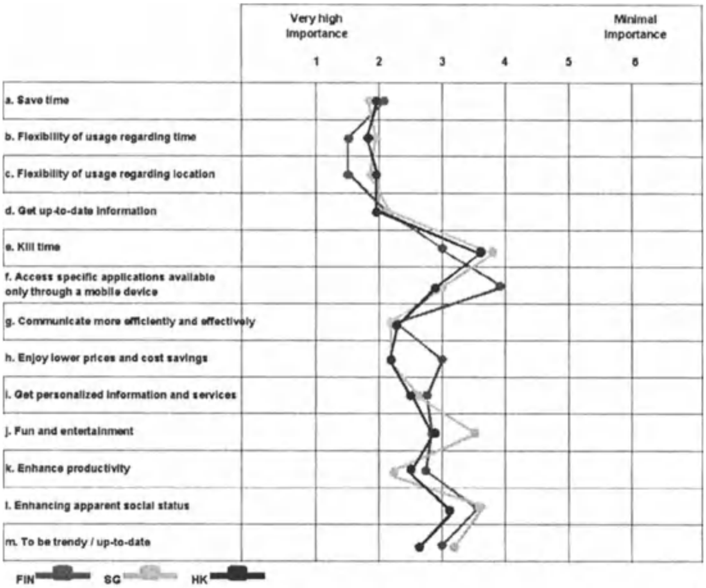
			a.	b.	c.	d.	e.	f.	g.	h.	i.	j.	k.	l.	m.	n.	o.
FIN	n=31	average	3.0	1.8	3.3	2.8	3.4	4.0	3.6	3.4	2.8	3.6	3.8	2.4	3.1	4.4	4.6
		STDEV	1.4	0.9	1.1	1.0	1.3	1.3	1.2	1.2	1.3	1.3	1.4	1.2	1.2	1.1	1.4
SG	n=28	average	2.6	2.3	3.1	3.0	3.1	3.6	3.8	2.9	2.6	1.0	3.3	3.1	3.3	4.1	3.8
		STDEV	1.4	1.3	1.0	0.9	1.1	1.3	1.0	1.2	1.1	0	1.3	1.4	1.1	1.1	1.4
HK	n=31	average	2.2	2.5	2.9	2.7	2.5	3.1	3.5	2.6	2.3	1.0	3.7	2.6	3.1	4.3	1.5
		STDEV	1.2	1.4	1.4	1.4	1.6	1.4	1.5	1.4	1.4	0	1.6	1.4	1.2	1.4	1.5

Figure 7.3. Likelihood of achieving a satisfactory level of turnover for the m-commerce products and services.

products and services must add significant perceived value to the customers.

The experts' opinions support the Keen and Mackintosh propositions, i.e. customers go wireless because of the high level of flexibility that the mobile devices offer both in terms of time and place. Other reasons are to improve productivity in terms of saving time, and to get up-to-date information. There are many studies, which point to the benefits of timeliness, location or convenience for users.

Things, which have to do with the customers' social status, do have some importance, but these factors are not as important as one would



			a.	b.	c.	d.	e.	f.	g.	h.	i.	j.	k.	l.	m.
FIN	n=31	average	2.1	1.5	1.5	2.1	3.0	3.9	2.3	3.0	2.7	2.8	2.7	3.5	3.0
		STDEV	1.0	0.6	0.7	1.0	1.4	1.4	1.2	1.2	1.2	1.2	1.2	1.4	1.1
SG	n=28	average	1.8	1.9	1.8	2.1	3.8	3.0	2.2	2.2	2.6	3.5	2.3	3.5	3.2
		STDEV	0.9	0.9	0.9	1.1	1.3	1.3	1.0	1.0	1.1	1.2	0.9	1.5	1.5
HK	n=31	average	1.9	1.8	1.9	1.9	3.6	2.9	2.3	2.2	2.5	2.9	2.5	3.1	2.6
		STDEV	1.3	1.2	1.3	1.3	1.3	1.4	1.4	1.3	1.2	1.2	1.3	1.5	1.2

Figure 7.4. The relative importance of the motivations of current and future consumers of m-commerce products and services.

expect. Interesting is, that the experts do not think that access specific applications, that would be available only through a mobile device, would be of high importance. The experts in Hong Kong and Singapore concur on this view, but the Finnish experts think that this point is even less important. The experts may see mobile commerce as complementary to Internet commerce and not as a completely independent business environment. The question of complementary versus independent m-commerce services correspond also with the proposals brought by Cattaneo and Martinoli (2001) to different supplier business models and is a key aspect to take into account when analysing the potential demand.

The experts in Hong Kong and Singapore concur on the importance of lower prices and cost savings, which is seen as less important by the Finnish experts. There is also another (not very large) difference, the experts in Hong Kong and Finland regard fun and entertainment as potentially important applications, but they are found less so by the Singapore experts.

5. Mobile Commerce Products and Services

The lessons learned from our discussion of the key elements of m-commerce products and services from the consumer survey, from the expert surveys and from the work by Keen and Mackintosh (2001) point to a number of core issues, which we at this point believe will play some role in deciding the future of m-commerce.

M-commerce products and services will to a large extent be information systems, which are built as systems of modules, which in turn consist of layers for specific features and functionality. Products and services may be bundled together in order to offer enhanced or advanced products and services. The bundles are formed by interconnected information systems, in which the connections are worked out through either the layers or the modules (cf. Fig. 7.5). This forms the basis for the building of *new customer relationships*, as these will be handled through software, which offers the means for new relationships designs. If the interaction with customers is to be run with software support on mobile devices, we will be forced to find simple but value-adding solutions, i.e. there will be the need for rather a complete business process reengineering.

If we build new customer relationships, we should gear these to a *redesign of the supply chain* and to new principles for supply chain management. This follows naturally from the concentration of the customer interface to software, which opens the road for building supply chain and logistics solutions with information systems, which integrate to the customer interface solutions. In this way, there is some substance to the claim that m-commerce will form the basis for new forms of commerce and for new business models.

Keen and Mackintosh take a few more steps (cf. (2001)) as they propose that m-commerce will cause a mobilization of the knowledge resources of an organization. This contention can again be understood as a consequence of the technology developed for the forming of new customer relationships and the redesign of the supply chain - this technology can be used internally in a company to simplify the internal logistics networks.

This was supported in the expert survey, in which the most important motivations for m-commerce were: (i) saving time, (ii) flexibility of usage regarding time, (iii) flexibility of usage regarding location, and (iv) getting up-to-date information. Even if these observations refer to the m-commerce products and services, the technology can be used for company-internal purposes as well, and will then have the effects proposed by Keen and Mackintosh.

The key question for m-commerce is to find some way to judge the user-value of products and services, i.e. to find the applications, which will form the basis for viable business models. In Keen and Mackintosh (2001) the *Braudel Rule* is proposed: *freedom becomes value when it changes the limits of the possible in the structure of everyday life.* This is a very good insight, as it offers a way to screen out products and services offering only *convenience* (like saving time and effort, but they will not change the limits of the possible) or being only a *feature* (offering new options within existing routines). The freedom can be worked out in three different aspects: (i) relationship freedoms, which add value to the customer relationships, (ii) process freedoms, which add value to the supply chain, in logistics and in business partner relationships, and (iii) knowledge freedoms, which add value through knowledge mobilisation.

A surprising observation is that the freedom test can be worked out in terms of the systems structure we have developed in Fig. 7.5. First of all, the freedom dimensions get different interpretations for the customer, the producer and the management perspectives, and it may be the case that product and service features, which fail "the freedom test" for the customer, may be freedom features for the producer and management. Second, the customer may have different "freedom attributes" as an individual as compared to when he/she is the member of a team, a group (with some shared value structure), a family, a work community or a leisure time community. Third, there appears to be different "freedom attributes" for work roles and the roles individuals have in their free time, as the relevance and importance of timeliness, localisation and personalisation (which we identified as key features in Fig. 7.5) get different emphasis.

In our expert survey, SMS is jointly identified as a key m-commerce service, which is likely to achieve a satisfactory level of turnover. The SMS if identified in many studies as "freedom service" and there is no doubt that millions of teenagers all over Europe regard it as a way of "changing the limits of the possible in the structure of everyday life". It is easy to see that SMS for the customer is a communication tool in both work-related activities and in free time activities - but it is used differently. The producers (the network operators) strive to build add-on activities and services to the SMS in order to increase the use of network time, and to perhaps create new products and services, which will again have the "freedom attributes" for customers. Seen from a management perspective, the SMS is a way to save costs and resources for exchange of information, to carry out real time co-ordination, to facilitate teamwork, etc.; this will again attract the attention of the producers, which will try to build add-on products and services to facilitate the management applications; if they are successful, these products and services will again have the "freedom attributes" for the customers and be adopted. And so on.

Let us introduce some structure into this discussion of what constitute the key success factors and propose some classifications along three perspectives: the customer, the producer and the management.

Seen from the perspective of the *customer* the necessary distinguishing elements are:

1 flexibility, m-commerce products and services should be available anywhere, at any time and anyhow.

2 value-adding, m-commerce products and services should improve productivity, they should be adaptive to localization and they should be sensitive to customer personalization.

3 a mobile technology basis, m-commerce products and services should use innovative and distinguishing features of mobile technology to enhance the quality of life (e.g. messaging, entertainment, education, information, privacy, etc.).

Seen from the perspective of the *producer* the necessary distinguishing elements are

4 modularity, m-commerce products and services could be built from a core of generic product and service modules, which can be combined to form context adapted products and services; this should support the flexibility element.

5 layers, m-commerce products and services could be built in layers to add attributes and characteristics, which are adapted to (i) customer personalization, (ii) localization, (iii) brand profiles, (iv) privacy, etc.; this should support the value-adding element.

6 bundling, m-commerce products and services could be built through a bundling of modular products and services, which would be a way to make use of the mobile technology basis. Bundling can be done through modules and layers, but can also be mobile technology based.

Seen from the perspective of the *management* the necessary distinguishing elements are

7 value/cost ratios, m-commerce products and services should show good or very good value for cost in comparison with similar products and services; this should form the basis for pricing strategies, and cost and revenue models.

8 production, logistics, marketing and advertising, m-commerce products and services should have innovative features in comparison with similar products and services; this may be a function of the possibilities of- fered by the mobile technology.

9 business model, m-commerce products and services should use innovative and distinguishing features of mobile technology to support new business models.

We can combine all these elements in an intuitive graphical description (cf. Fig. 7.5).

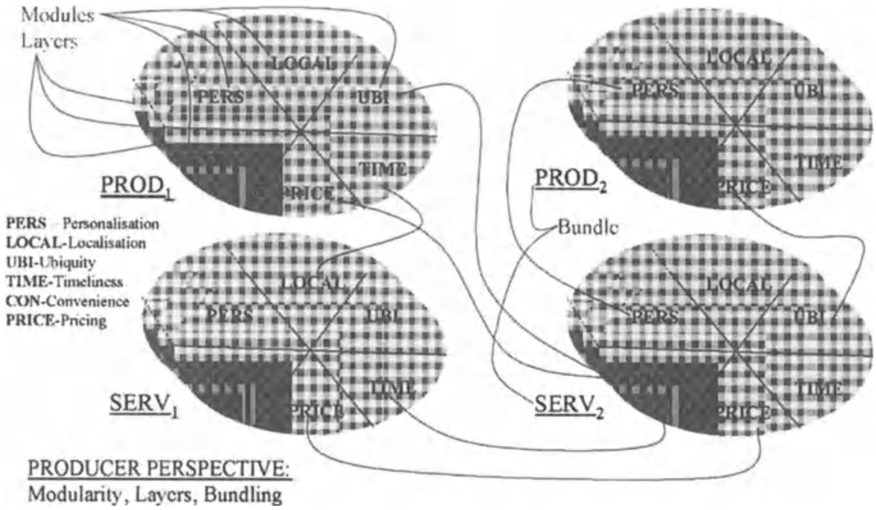


Figure 7.5. M-commerce, key elements of products and services.

In Fig. 7.5, products and services are shown as "thick sets", which are built with multiple layers (cf. the producer perspective), and each layer may be defined by multiple attributes, which may be the same or different for each layer. The products and services are described with multiple attributes, which represent, for instance, the key success factors, the distinguishing elements (from the user, producer or management perspectives), or some other features, which are essential for the design of good m-commerce product and service combinations.

The attributes can be specific for modules and/or layers, and they can be defined for specific products and services, or be specific for bundles of products and services. It appears that we with these simple elements can describe a considerable variety of m-commerce product and service alternatives.

As the distinction between products and services may become blurred as they are produced with digital mobile technology we need to introduce the following distinctive elements:

- *services*: intangible, no ownership is defined;
- *products*: tangible, ownership is defined;
- *digital products*: intangible, ownership is defined
- *digital services*: intangible, no ownership is defined;
- *digital product & service*: intangible, ownership is defined;
- *digital service & product*: intangible, ownership is not defined;

The last two cases point to the possibility that we have proprietary services as part of digital products or that services may have products incorporated, for which no ownership can be claimed. It appears that ownership is a key feature for products - a key feature for services is that the client's presence is needed. This may then serve as a guideline for building m-commerce products and services.

The recent debate about the Napster Internet-site shows that the distinction between products and services is not that clear, and that producers of m-commerce products and service may have problems getting their rights defined and recognized. This is again a key issue for securing revenue from mobile commerce.

The copyright to material on the Internet has also recently been debated as David Brooks found out that large parts of the material he collected over five years for his site www.vangoghgallery.com had been copied and used for a competing site - his ownership was not recognized in the court (now the site is owned by Barewalls.com and it is not possible to copy Van Gogh paintings anymore).

The quest for killer applications, which is a common feature in most of the business seminars sold by the key e-business consulting companies, may be a quest in vain. Already from the elements we have introduced above it appears evident that single, outstanding killer applications may be rare and far between. This has also been visible in discussion of m-commerce products and services, in which we have various types of combinations:

- *Killer Cocktail*, a mix in which the components cannot be distinguished (Nokia);
- *Killer Pizza*, a mix in which the components can be distinguished;
- *Killer Bouquet*, a set of components for which the aggregate is more than the sum of its parts (the one we have chosen as our metaphor);
- *Killer Soup*, the more ingredients you put in, the better it gets - an operator will be needed for stirring;
- *Killer Fondue*, as for the soup, but no operator is needed for stirring;

Using these, no doubt rather stirring metaphors, the "killer bouquet" is a bundle of m-commerce products and services, i.e. the type of combination we have s hown in Fig. 7.1.

With an understanding of the key features and success factors it appears that the core of the m-commerce products and services is, (i) to develop value-added content, (ii) to make them localization adaptive, (iii) to make them flexible to localization, (iv) to make bundles of products and services ubiquitous and adaptive to moving customers, (v) to ensure timely delivery, and (vi) to build or enhance user freedom.

It is intuitively appealing to try to build the products and services of the m-commerce domain with advanced, intelligent information technology for several reasons.

First of all, the m-commerce domain requires fast planning, problem solving and decision-making, and intelligent support technology will reduce both the number of errors and the magnitude of the errors.

Secondly, support should be available at the moment of decision-making, in an appropriate form and with the best possible substance.

Thirdly, intelligent information technology is a variety of technologies, ranging from machine intelligence, through artificial neural nets, genetic algorithms and case-based reasoning to soft computing, which is built on fuzzy logic, approximate reasoning and computing with words (cf. Carlsson (1997, 2002)).

The field of agents is rich and diverse, yet fragmented. The word "agent" is nowadays so widely used that it is best described as an umbrella term for a heterogeneous body of research and development. Different communities refer to it in different ways and it bears multiple names and forms in different contexts as it comes in many physical guises: *robots, daemons, knowbots, softbots, taskbots, userbots, personal agents, personal assistants* and so on (cf. Jennings and Wooldridge (1998), Jennings et al (1998), King and O'Leary (1996), Maes (1994), McKie (1995), Negroponte (1997), Nwana (1996), Nwana and Ndumu

(1997)). To get a general picture of the agent world, Franklin and Graesser's (1996) agent tree is very helpful.

In this context we are interested in software agents. Similarly, there seems to be almost as many definitions of software agents as researchers since no two developers appear to share exactly the same opinion on what constitutes a software agent (cf. Jennings and Wooldridge (1998)). Nevertheless, the automation of work and the automation of work with computers are central to the idea of software agents. Kay (1984) described software agents as soft robots living and doing its business within the computer's world. Cheong (1996) described software agents as primarily human-delegated software entities that can perform a variety of tasks for their human masters. Maes (1994) described a software agent as its user's personal digital assistant that provides personalised assistance in a specialised task.

We agree with Jennings and Wooldridge (cf. (1998)) that most agent researchers would find themselves in broad agreement with the following key principles in the definition of software agents and agent-based systems:

Software agents are computational programs or entities situated in a computing environment and assisting users with computer based tasks. They act to accomplish specialized tasks on behalf of users and act towards reaching certain user-specified or automatically generated goals with a certain degree of autonomy and flexibility (cf. Franklin and Graesser (1996), Negroponte (1997), Nwana (1996)). Agent-based systems refer to systems in which the key abstraction used, either in conceptualisation, design, or implementation, is that of an agent (cf. King and O'Leary (1996)).

The key attributes emphasised here are (i) situation awareness, (ii) autonomy and (iii) flexibility. *Situation awareness* means that an agent receives sensory input from its environment and that it can perform actions, which change the environment in certain ways. *Autonomy* means that the system is able to take initiative, to solve problems without direct intervention or constant guidance from a user or other agents, and it has control over its own action and internal state. To be *flexible* means that the system is *responsive, adaptive or robust*, which again requires that it perceives the environment and responds in a timely fashion to changes, which occur in it, and takes account of changing user needs and a changing task environment.

In this way, an agent system comes to know about the user's preferences and can tailor interactions and actions to reflect them. Finally, an agent system can be made proactive. Then it not simply acts in response to the environment, but it is also able to exhibit opportunistic, goal-oriented behaviour and to take the initiative where appropriate. It does not wait to be told what to do next - rather it makes suggestions to the user (cf. Nwana and Ndumu (1997)).

In addition to this, other often mentioned important properties of software agents include sociability or co-operative ability, mobility, learning ability, and intelligence (cf. Nwana (1996)). When deemed appropriate, an agent should be able to interact with other agents or a human user in order to complete their own problem solving and to help others with their activities. An agent's capability to personalise or customise its assistance depends on its capability of adaptation and learning ability. Agents can play different types of roles and accomplish different tasks and responsibilities.

Depending on their role definitions, different agents tend to differ in their co-operation ability, intelligence, mobility and autonomy. An agent, which is built to offer decision support functionality, will act autonomously and proactively to gather information and to make recommendations. The human user of the agent will, nevertheless, make the final decision. In contrast, an agent may also assume a completely autonomous role and take responsibility for the whole process of problem solving. Not all agents can exhibit smart problem solving behaviour, some do and are limited by the current state of the art in related fields. In some cases the individual agents of a system may not be that advanced at all, but in combination and co-operation they form agent-systems with effective and advanced features (cf. King and O'Leary (1996)).

The very first idea of the agent approach suggests the delegation of tasks and responsibility. Such an approach allows users to move away from computing details while focusing on more conceptual constructs. It reduces complexity and increases efficiency and the delegation of functions supports user mobility (cf. Carlsson (2000), Maes (1994), McKie (1995)). Agents can be used to solve new types of problems and to build new applications that were previously too complicated to build. The agent concept makes it natural, easier and advantageous to conceptualise problem domains of a complex nature. If a problem domain is particularly complex, large, open-ended or unpredictable (the structure is capable of dynamic changing, e.g. the Internet), then the agent approach presents a good alternative solution (cf. Jennings et al (1998), Nwana (1996)).

For the same reason, software agents also offer an alternative solution to improve the efficiency of software development. As is widely known, the most powerful tool for handling complexity in software development is modularity and abstraction. Software agents present a natural metaphor and a powerful tool for making systems modular and offer a better means for conceptualising, designing and implementing applications. In many cases, real-world entities and their interactions can be directly mapped into problem solving agents with their own resources and expertise (cf. Jennings et al (1998), Nwana (1996)).

The abstraction at the user level enables agent systems to marry underlying system complexity with a high level of user friendliness. They encapsulate hardware or software changes inside themselves without making users aware of them, users are only aware of the functionality or service changes. In fact, software agents are establishing a new paradigm for human-computer interaction that is less like the traditional master-slave relationship and more like a partnership. The dominant, standard interface of computer applications has been direct manipulation (see-and-point interfaces), which means that a program will only do something that a user explicitly tells it to do. It is a one-way interaction; it requires software objects to be visible and it constantly informs the user about the kind of things he can act upon. For many of the user tasks direct manipulation is a distinct improvement over command-line interfaces. However, many of its advantages begin to fade as tasks grow in scale or complexity. There are often times, when sequences of actions could be better automated than directly performed by the user in simple, tedious steps. It would be desirable to have programs that in certain circumstances could take the initiative, rather than wait for the user to tell exactly what they want (cf. Bradshaw (1997), Jennings and Wooldridge (1998)). Software agents bring about an indirect interfacing approach (ask-and-delegate).

In summary, agent systems differ from and complement traditional decision support systems mainly in four aspects.

First, traditional systems are functional, which means that they work simply by taking some input, computing a function of it and giving this result as output. They do not interact directly with any environment. They receive information but not via sensors, rather through a user acting as a middleman. In the same way they do not act on any environment, rather they give feedback information or advice to a third party (cf. Jennings et al (1998)). They usually remain dormant until specifically called by user instructions. On the other hand, agent systems - as reactive systems - maintain an ongoing interaction with the environment and can act on the environment (cf. Franklin and Graesser (1996)). Because of this, agent systems can work in both real time processing (user initiated) and in batch processing (a scheduled time or conditioned time). Agents are always "alive" and ready for action, and they do not rely on users' explicit actions to be activated. They work in the background, serve around-the-clock, and perform automatic actions at the user-level of abstraction (cf. Maes (1994), McKie (1995)).

Second, traditional systems always depend on users to explore and use them. The users typically have to describe each step that needs to be performed to solve a problem, down to the smallest level of detail (cf. Jennings et al (1998)). With agent systems users need only specify a high-level goal instead of issuing explicit instructions, and can leave the 'how' and 'when' decisions to the agents. Agent systems make it possible for the programs to work independently of the users' presence and instructions, and to deliver only customised user-wanted information and service (cf. Jennings et al (1998), Maes (1994), McKie (1995)). As Negroponte (1997) claimed, the future of computing will be 100% driven by delegating to, rather than manipulating computers.

Third, the agent approach adds diversity and competitive value to existing systems. Applications with agent functionality possess competitive advantage to those without it. Agents make it easier to supply customised computing products and services than conventional systems. They provide products that are easier to use, bypass intermediaries between products/services and customers (users), eliminate delay in the process and free up human resources (time, cognitive efforts) for other work.

Fourth, agent wrappers can be built around legacy systems to enable them to interoperate with other systems (cf. Franklin and Graesser (1996)).

In addition to the individual agent features we have just worked through, there is some work done on creating a class of *collaborative agents*, which will have both individual features and features they get through the collaboration (cf. Nwana and Ndumu (1997)). Collaborative agents emphasise autonomy and co-operation with other agents in order to perform tasks for their users in open and time-constrained multi-agent environments. The may have some (limited parametric) learning properties for autonomous work and they may have to "negotiate" in order to reach mutually acceptable agreements with other agents.

The motives for building a collaborative agent system include: (i) solving problems that may be too large for a centralised single agent, (ii) allowing for the interconnecting and interoperation of existing legacy systems (e.g. decision support systems, conventional software systems, etc.), and (iii) providing solutions to inherently distributed problems, such as drawing on distributed data sources or distributed sensor networks. The PLEIADES (cf. Nwana and Ndumu (1997)) project developed collaborative agents for organisational decision making over the "info-sphere", which actually was a collection of Internet-based heterogeneous resources.

Individually, an agent was built as a planning module in the PLEIADES, which is linked to a local facts and beliefs database. It also has a local scheduler, a coordination module and an execution monitor. It appears that a number of these principles will be useful for the flexible support environments we outlined for the mobile applications domain.

The world of collaborative agents is being extended to the multi-agent (MA) systems. The MA systems are gaining in acceptance especially for Internet applications such as electronic commerce, virtual enterprises, (shared) scientific computing, intelligent manufacturing, home automation, component based software construction and power distribution management. The MA systems allow sets of agents with differing capabilities to interact to solve problems, they allow for scalability, they permit us to reuse software modules, they handle software evolution and they promote open systems.

There are a number of applications available in the market to illustrate how these systems are designed, built and implemented[3].

A project called SciAgents has developed an MA system to support networked scientific computing. Here the MA system allows scientists to view networked hardware and software resources as a single, virtual meta-computer. This has been described for many years already in a number of projects, but only the arrival of the MA technology has made it feasible in practice to build affordable virtual meta-computers. Collaborating agents locate, combine and invoke the resources needed to solve given (often complex) problems (cf. Nwana (1996), Nwana and Ndumu (1997)).

It should probably be pointed out that software agents do not have features equivalent to human intelligence - despite the often-used misnomer "intelligent agents". In order to bring some structure to the capabilities of software agents a heuristic measure called "intelligence density" (ID) has been defined along the following lines, where the levels denote agent capabilities:

<u>Level I</u>. Will condense data from many data sources

<u>Level II</u>. Will clean data [scrubbing, integrating, transforming]

<u>Level III</u>. Will discover patterns in sets of data

<u>Level IV</u>. Will have some capability to learn [or "learn"]

The "learning" capability is a possibility but in no way a certainty. The "understanding", which is quite often mentioned in sales talk, re-

[3]cf. Communications of the ACM, March 1999, for a series of articles on MA systems.

quires semantic understanding, which is a feature for the future. This would represent ID-level V.

For MA systems to succeed, a systematic collaboration of agents is necessary. This, again, requires that the agents have been designed and built in such a way that the internal cognitive structure of the agents is conducive to collaboration. If this is the case, then there is basis for building MA systems with some learning and planning capabilities. As is gradually becoming apparent, the learning and planning capabilities reside in the interaction of agents and probably not with the individual agents

Most of the agent technology has been developed for well-structured environments, and we should note that the planning, problem-solving and decision-making environments we are dealing with in mobile applications domain are ill structured, evolving, developing and changing very quickly. That is why the basis for new generations of software agents is built on fuzzy logic, and the theory and technology of approximate reasoning.

The key attributes emphasised for agents are (i) *situatedness*, (ii) autonomy and (iii) flexibility. Situatedness means that an agent receives sensory input from its environment and that it can perform actions, which change the environment in certain ways.

Autonomy means that the system is able to take initiative, to solve problems without direct intervention or constant guidance from a user or other agents, and it has control over its own action and internal state. To be *flexible* means that the system is *responsive, adaptive or robust*, which again requires that it perceives the environment and responds in a timely fashion to changes, which occur in it, and takes account of changing user needs and a changing task environment. In this way, an agent system comes to know about the user's preferences and can tailor interactions and actions to reflect them. Finally, an agent system can be made proactive. Then it not simply acts in response to the environment, but it is also able to exhibit opportunistic, goal-oriented behaviour and to take the initiative where appropriate.

The attributes (i)-(iii) are similar to those used to describe the *flexibility*, the *value-added* and the *bundling* features of m-commerce products and services. We have even been able to demonstrate with some multi-agent system prototypes[4] that software agents actually can be used to produce these features.

[4]The Imagine21 project, which was run as an ESPRIT project 1998-2000.

Modern support systems research is focused on the *theory and applications of intelligent systems and soft computing in management* (cf. Carlsson (1997), Carlsson and Walden (2000)). *Soft computing* includes research on fuzzy logic, artificial neural nets, genetic algorithms and probabilistic modelling. The added feature to the *intelligent systems* is that in soft computing the machine learning systems are developed using fuzzy logic and the fuzzy sets theory as a theoretical and methodological basis. Work is under way to develop support systems for m-commerce, which include intelligent modules built from soft computing components.

It appears to be the case that the evolution path of future m-commerce products and services can be understood only if we are able to find truly generic components (of the type introduced in Fig. 7.5), which can be used as platforms for future generations of enhanced mobile services. Generic components can be enhanced with more and more advanced features offering different levels and categories of value-adding to the user. The generic constructs need an operating platform, through which data conversion can be managed and controlled, and device interface protocols can be defined and built. The platform for the agent technology, which serves as the basis for the mobile commerce products and services is typically a standard J2EE Server construct (cf. Fig. 7.6), which in our case is being integrated with a multi-channel server platform for administrating the back-office routines for authentication, security, payments, logistics, etc.

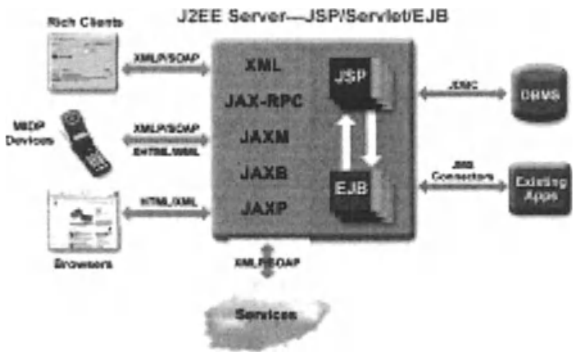


Figure 7.6. Mobile commerce platform.

Seen from the perspective of generic components and operating platforms the mobile products and services are quite different from the view offered the end users, for whom they are click-able functions on the small screens of mobile phones. It appears that the technology roadmap, which will describe the evolution path of future generations of mobile products and services, will be quite different when constructed from the generic components as compared to the everyday use of click-able functions. This may be a reason for the wildly fluctuating forecasts of the future m-commerce markets.

References

[1] Anckar, B. (2002a), "Rationales for Consumer Adoption or Rejection of E-Commerce: Exploring the Impact of Product Characteristics". Proceedings of the SSGRR 2002s Conference, L'Aquila, Italy, July 29 - August 4, 2002.

[2] Anckar, B. (2002b), "Motivators for Adoption of Mobile Commerce: Findings from a National Consumer Survey". Proceedings of the International Conference on Decision Making and Decision Support in the Internet Age (DSIage 2002), Cork, Ireland, July 4-7, 2002, pp. 749-762.

[3] Anckar, B., and D'Incau, D. (2002), "Value Creation in Mobile Commerce: Findings from a Consumer Survey". Journal of Information Technology Theory and Application, Vol. 4, No. 1, pp. 43-64.

[4] Beck, J. and Wade, M. (2003), DoCoMo, Japan's Wireless Tsunami. Amacom, New York.

[5] Booz, Allen & Hamilton (2001), Nuturing the New Wireless Innovators. Available at: www.bah.de/content/publikationen_events/5a_telekommunikation.asp

[6] Booz, Allen & Hamilton (2000), The Wireless Internet Revolution, Insights, The Communications, Media & Technology Group (6:2), pp. 1-8. Available at: www.bah.de/content/publikationen_events/5a_telekommunikation.asp

[7] Bradshaw, J. (1997), "Introduction to Software Agents", in Jeffrey Bradshaw (Ed.), Software Agents, AAAI Press/The MIT Press, 1997, pp. 3-46

[8] Buellingen and Woerter (2002), "Development Perspectives, Firm Strategies and Applications in Mobile Commerce", Journal of Business Research 5830 (in press).

[9] Carlsson, C. (1997), "Fuzzy Logic and Hyperknowledge: A New Effective Paradigm for Active DSS". Proceedings of HICSS-30, IEEE Computer Society Press, Los Alamitos 1997, pp 324-333

[10] Carlsson, C. and Walden, P. (2000), Intelligent Support Systems - The Next Few DSS Steps, Human Systems Management, Vol 19, 2000, pp 135-147

[11] Carlsson, C. (2000), Mobile Commerce and Value-Added Services. The Impact of Intelligent IT, in L. Methlie (ed.): The New Economy - Dröm eller virkelighed?, Fagbokforlaget, Bergen 2000, pp 107-130

[12] Carlsson, C., Walden, P. and Liu, S. (2000), Industry Foresight with Intelligent Agents, Human Systems Management, Vol 19, 2000, pp 169-180.

[13] Carlsson, C. (2002), "The Mobile Process Edge: An Outline of a New Research Area", DSIAge2002, Cork, Ireland 2002

[14] Carlsson, C. and Walden, P. (2001), "The Mobile Commerce Quest for Value-Added Products and Services", Proceedings of the SSGRRs 2001, L'Aquila 2001

[15] Carlsson, C. and Walden, P. (2002a), "Further Quests for Value-Added Products and Services in Mobile Commerce", ECIS 2002 Proceedings, Gdansk, Poland 2002

[16] Carlsson, C. and Walden, P. (2002b), "Extended Quests for Value-Added Products and Services in Mobile Commerce", DSIAge 2002 Proceedings, Cork, Ireland 2002

[17] Carlsson, C. and Walden, P. (2002c), "Mobile Commerce: A Summary of Quests for Value-Added Products and Services", 15th Bled International Conference on E- Commerce, Bled, Slovenia 2002

[18] Carlsson, C. and Walden, P. (2002d), "Mobile Commerce: Some Extensions of Core Concepts and Key Issues". Proceedings of the SSGRR 2002s Conference, L'Aquila, Italy, July 29 - August 4, 2002.

[19] Cattaneo, G. and Martinoli, M. (2001). The Evalution of Third generation Mobile Markets in Europe, Star Issue Report N.12, July 2001.

[20] Cheong, F.-C. (1996), Internet Agents: Spiders, Wanderers, Brokers and Bots, New Riders Publishing, Indianapolis, 1996

[21] Davis, F.D. (1989), "Perceived Usefulness, Perceived Ease of Use, and User Acceptance of Information Technology". MIS Quarterly, Vol. 13, Issue 3, pp. 319- 340.

[22] Durlacher Research Institute (March, 2001), UMTS Report, Durlacher Research Report, available at http://www.durlacher.com

[23] Eggert, A., and Ulaga, W. (2002), "Customer Perceived Value: A Substitute for Satisfaction in Business Markets?" Journal of Business and Industrial Marketing, Vol. 17, No. 2.

[24] Eikebrokk, T.R., and Sørebø, Ø. (1998), "Technology Acceptance in Situations with Alternative Technologies", Norsk konferanse for organisasjoners bruk av informasjonsteknologi, Oslo, Norway, 17-19 July, 1998, pp. 89-97.

[25] Franklin, S. and Graesser A. (1996), Is It an Agent or just a Program? A Taxonomy for Autonomous Agents, Proceedings of the Third International Workshop on Agent Theories, Architectures and Languages, Springer-Verlag, Heidelberg, 1996.

[26] Furnell, S.M., and Karweni, T. (1999), "Security Implications of Electronic Commerce": A Survey of Consumers and Businesses. Internet Research: Electronic Networking Applications and Policy, Vol. 9, Issue 5, pp. 372-382

[27] Gillick, K., and Vanderhoof, R. (2000), "Mobile E-commerce: Marketplace Enablers and Inhibitors". Paper presented at the Smart Card Forum Annual Meeting, September 25-28, 2000. Available at: www.datacard.com/downloads/pdf/white_paper_ecommerce.pdf

[28] Green, R. (2000), "The Internet Unplugged". eAI Journal, October 2000, pp. 82-86.

[29] Guerley, W. (2000), "Making Sense of the Wireless Web", Fortune, August 15. Available at: www.fortune.com

[30] Hampe, J.F., Swatman, P.M.C., and Swatman, P.A. (2000), "Mobile Electronic Commerce: Reintermediation in the Payment System", Proceedings of the 13th Bled International Electronic Commerce Conference, Bled, Slovenia, June 19-21, 2000, pp. 693-706.

[31] Han, J., and Han, D. (2001), "A Framework for Analyzing Customer Value of Internet Business", Journal of Information Technology Theory and Application, Vol. 3, No. 5, pp. 25-38.

[32] Herman, J., and Neff, T. (2002), "Managing through the M-Commerce Storm". World Market Series Business Briefings: Wireless Technology 2002. World Markets Research Centre, 2002, pp. 78-82.

[33] Jennings, N. R. and Wooldridge, M. (1998a), "Applications of Intelligent Agents", in Nicholas R. Jennings and Michael J. Wooldridge (Ed.), Agent Technology Foundations, Applications, and Markets , Springer-Verlag, 1998.

[34] Jennings, N. R., Sycara, K. and Wooldridge, M. (1998b), "A Roadmap of Agent Research and Development", Autonomous Agents and Multi-Agent Systems, 1, 7-38 (1998), Kluwer Academic Publishers, Boston

[35] Kalakota, R., and Robinson, M. (2001), M-Business: The Race to Mobility. New York: McGraw-Hill.

[36] Kay, A. (1984), "Computer Software", Scientific American, 251 (3), 1984, 53-59

[37] Keen, P., and Mackintosh, R. (2001), The Freedom Economy: Gaining the M-commerce Edge in the Era of the Wireless Internet. Berkeley, CA: Osborne/McGraw-Hill.

[38] King, D. and O'Leary, D. (1996), "Intelligent Executive Information Systems", IEEE Expert, December 1996, pp. 30-35

[39] Langendoerfer, P. (2002), "M-commerce: Why it Does Not Fly (Yet?)". Proceedings of the SSGRR 2002s Conference, L'Aquila, Italy, July 29 - August 4, 2002.

[40] Lee, D., Park, J. and Ahn, J. (2001), "On the Explanation of Factors Affecting E- Commerce Adoption". Proceedings of the 22nd International Conference on Information Systems , New Orleans, Louisiana, December 16-19, 2001, pp. 109-120.

[41] Lee, W.J., Kim, T.U., and Chung, J-Y. (2002), "User Acceptance of the Mobile Internet", Proceedings of the First International Conference on Mobile Business, Athens, Greece, July 8-9, 2002.

[42] Li, V.K. (2002), "Global M-commerce - Business Opportunities for Wireless Data Services"; in World Market Series Business Briefings: Wireless Technology 2002. World Markets Research Centre, 2002, pp. 123-126

[43] Luckett, M., Ganesh, J., and Gillett, P. (1999), "Quantitative Tools in Tourism Research: An Application of Perceptual Maps"; in Pizam, A., and Mansfeld, Y. (Eds.), Consumer Behavior in Travel and Tourism (pp. 307- 333), Binghamton, NY: The Haworth Hospitality Press.

[44] Maes, P. (1994), "Agents that Reduce Work and Information Overload", Communications of the ACM, Vol. 71, No. 7, pp. 31-40, July 1994

[45] Malhotra, Y., and Galletta, D.F. (1999), "Extending the Technology Acceptance Model to Account for Social Influence: Theoretical Bases and Empirical Validation". Proceedings of the 32nd Hawaii International Conference on System Sciences, Maui, Hawaii, January 5-8. Los Alamitos: IEEE Computer Society Press.

[46] Mathieson, K., Peacock, E., Chin, W.W. (2001), "Extending the Technology Acceptance Model: The Influence of Perceived User Resources". The Data Base For Advances in Information Systems, Vol. 32, No. 3 (Summer), pp. 86-112.

[47] May, P. (2001), Mobile Commerce: Opportunities, Applications, and Technologies of Wireless Business, Cambridge University Press.

[48] McDougall, G.H.G., and Levesque, T. (2000), "Customer Satisfaction with Services: Putting Perceived Value into the Equation", Journal of Services Marketing (14:5), 2000, pp. 392-419.

[49] McKie, S. (1995), "Software Agents: Application Intelligence Goes Undercover", DBMS Magazine, Vol. 8, No. 4, April 1995

[50] McClelland, S. (2002). Ultimate Telecom Futures, Broadband Multi-Service Networks, Horizon House Publications, London.

[51] MobileInfo, News Issue #2003-06 (February 2003), Europeans Willing to Pay Extra for 3G Services, available at http://www.mobileinfo.com

[52] Müller-Versee, F. (1999), Mobile Commerce Report. London: Durlacher Research Ltd.

[53] Negroponte, N. (1997), "Agents: From Direct Manipulation to Delegation", in Jeffrey Bradshaw (Ed.), Software Agents, AAAI Press/The MIT Press, 1997.

[54] Nokia 3G Market Research Centre (2001). "Mcommerce: An end user perspective. Key Learnings from Global Research", Nokia 3G Market Research Report, Nokia Networks, May 25, 2001. Available at: www.nokia.com/3G

[55] Nwana,, H. S. (1996), "Software Agents: An Overview", Knowledge Engineering Review, Vol. 11, No. 3, pp. 1-40, September 1996, Also available at: http://www.cs.umbc.edu/agents/introduction/ao

[56] Nwana, H.S. and Ndumu D.T. (1997), "An Introduction to Agent Technology", in Nwana and Azarmi (eds.): Software Agents and Soft Computing, Springer-Verlag, Berlin 1997

[57] O'Cass, A.O. and Fenech, T. (2003), "Web Retailing Adoption: Exploring the Nature of Internet Users Web Retailing Behaviour", Journal of Retailing and Consumer Services (in press).

[58] Paavilainen, J. (2002), Mobile Business Strategies, Wireless Press, Addison-Wesley, Reading 2002

[59] Parasuraman, A. (1997), "Reflections on Gaining Competitive Advantage Through Customer Value". Journal of the Academy of Marketing Science, Vol. 25, No. 2, pp. 154-161.

[60] Pavlou, P.A. (2002), "What Drives Electronic Commerce? A Theory of Planned Behavior Perspective", Proceedings of the Academy of Management Conference" Denver, Colorado, August 9-14, 2002.

[61] Pavlou, P.A. (2003), "Consumer Acceptance of Electronic Commerce - Integrating Trust and Risk with the Technology Acceptance Model", International Journal of Electronic Commerce, Vol. 7, No. 3 (forthcoming).

[62] Pedersen, P.E., Methlie, L.B., and Thorbjørnsen, H. (2002), Understanding Mobile Commerce End-user Adoption: A Triangulation Perspective and Suggestions for an Exploratory Service Evaluation Framework, Proceedings of the 35th Hawaii International Conference on System Sciences, January 7-10, Big Island, Hawaii. Los Alamitos, CA: IEEE Computer Society Press.

[63] Ropers, S. (2001), "New Business Models for the Mobile Revolution". eAI Journal, February, pp. 53-57.

[64] Senn, J.A. (2000), "The Emergence of M-Commerce". Computer (33:12), December 2000, pp. 148-150.

[65] Shuster, T. (2001), "Pocket Internet and M-Commerce - (How) Will it Fly?", February 1, 2001. www.gwu.edu/ emkt/Ecommerce/file/Mcommerce.pdf

[66] Strong, C., and Old, J. (2000), "How Can Mobile Developments Deliver Customer End-Value? White Paper on Mobile Internet Applications. NOP Research Group, London, November 2000.

[67] Sweeney, J.C., and Soutar, G.N. (2001), "Consumer Perceived Value: The Development of a Multiple Item Scale". Journal of Retailing, Vol. 77, pp. 203-220.

[68] Teo, T.S.H., Lim, V.K.G., Lai. R.Y.C. (1999), "Intrinsic and Extrinsic Motivation in Internet Usage". Omega - The International Journal of Management Science 27, pp. 25-37

[69] Urbaczewski, A., Wells, J., Suprateek, S., & Koivisto, M. (2002), "Exploring Cultural Differences as a Means for Understanding the Global Mobile Internet: A Theoretical Basis and Program of Research", Proceedings of the 35th Hawaii International Conference on System Sciences, Big Island, Hawaii, January 7-10, 2002. Los Alamitos, CA: IEEE Computer Society Press.

[70] Varshney, U., Vetter, R.J., and Kalakota, R. (2000), "Mobile Commerce: A New Frontier," Computer, Vol. 33, No. 10 (October), pp. 32-38.

[71] Varshney, U., and Vetter, R. (2001), "A Framework for the Emerging Mobile Commerce Applications", Proceedings of the 34th Annual Hawaii International Conference on System Sciences (HICSS-34), January 3-6, 2001, Maui, Hawaii, Los Alamitos: IEEE Computer Society.

[72] Venkatesh, V., and Brown, S.A. (2001), "A Longitudinal Investigation of Personal Computers in Homes: Adoption Determinants and Emerging Challenges". MIS Quarterly, Vol. 25, No. 1, pp. 71-102

[73] Vittet-Philippe, P. and Navarro, J.M. (2000), "Mobile E-Business (M-Commerce): State of Play and Implications for European Enterprise Policy", European Commission Enterprise Directorate-General E-Business Report, No. 3, December 6, 2000. Available at: www.ncits.org/tc_home/v3htm/ v301008.pdf

[74] Vos, I. And P. de Klein (2002). The Essential Guide to Mobile Business. Prentice Hall PTR, Upper Saddle River.

[75] Vrechopoulos, A.P., Constantiou, I.D., Mylonopoulos, N and Sideris, I. (2002), "Critical Success Factors for Accelerating Mobile Commerce Diffusion in Europe", Proceedings of the 15th Bled Electronic Commerce Conference, June 17-19, 2002, Bled, Slovenia.

[76] Yankee Group (2000), "Understanding the Needs of European Mobile Phone Users: Consumer Survey Results", Wireless/Mobile Europe Report, Vol. 4, No. 18 (November), The Yankee Group, Boston.

[77] Zeithaml, V.A. (1988), "Consumer Perceptions of Price, Quality and Value: A Means-End Model and Synthesis of Evidence," Journal of Marketing, 52 (July), pp. 2-22.

[78] Durlacher Research Institute (April, 2000), M-commerce, Durlacher Research Report, available at http://www.durlacher.com

[79] Durlacher Research Institute (March, 2001), UMTS Report, Durlacher Research Report, available at http://www.durlacher.com

[80] E-Commerce Times, July 2000, February 2001, www.ecommercetimes.com

[81] ETForecasts, February 6, 2001, www.etforecasts.com/pr/pr201.htm

[82] InfoWorld.com, January 3, 2001, www.infoworld.com/

[83] Mobilelnfo, News Issue #2003-06 (February 2003), Europeans Willing to Pay Extra for 3G Services, available at http://www.mobileinfo.com

[84] Mobilelnfo, News Issue #2003-09 (March 2003), US Market Passes 50% Penetration with CDMA Continuing to Dominate, www.mobileinfo.com

INTERNATIONAL SERIES IN OPERATIONS RESEARCH & MANAGEMENT SCIENCE

Frederick S. Hillier, Series Editor Stanford University

Saigal/ *A MODERN APPROACH TO LINEAR PROGRAMMING*
Nagurney/ *PROJECTED DYNAMICAL SYSTEMS & VARIATIONAL INEQUALITIES WITH APPLICATIONS*
Padberg & Rijal/ *LOCATION, SCHEDULING, DESIGN AND INTEGER PROGRAMMING*
Vanderbei/ *LINEAR PROGRAMMING*
Jaiswal/ *MILITARY OPERATIONS RESEARCH*
Gal & Greenberg/ *ADVANCES IN SENSITIVITY ANALYSIS & PARAMETRIC PROGRAMMING*
Prabhu/ *FOUNDATIONS OF QUEUEING THEORY*
Fang, Rajasekera & Tsao/ *ENTROPY OPTIMIZATION & MATHEMATICAL PROGRAMMING*
Yu/ *OR IN THE AIRLINE INDUSTRY*
Ho & Tang/ *PRODUCT VARIETY MANAGEMENT*
El-Taha & Stidham/ *SAMPLE-PATH ANALYSIS OF QUEUEING SYSTEMS*
Miettinen/ *NONLINEAR MULTIOBJECTIVE OPTIMIZATION*
Chao & Huntington/ *DESIGNING COMPETITIVE ELECTRICITY MARKETS*
Weglarz/ *PROJECT SCHEDULING: RECENT TRENDS & RESULTS*
Sahin & Polatoglu/ *QUALITY, WARRANTY AND PREVENTIVE MAINTENANCE*
Tavares/ *ADVANCES MODELS FOR PROJECT MANAGEMENT*
Tayur, Ganeshan & Magazine/ *QUANTITATIVE MODELS FOR SUPPLY CHAIN MANAGEMENT*
Weyant, J./ *ENERGY AND ENVIRONMENTAL POLICY MODELING*
Shanthikumar, J.G. & Sumita, U./ *APPLIED PROBABILITY AND STOCHASTIC PROCESSES*
Liu, B. & Esogbue, A.O./ *DECISION CRITERIA AND OPTIMAL INVENTORY PROCESSES*
Gal, T., Stewart, T.J., Hanne, T. / *MULTICRITERIA DECISION MAKING: Advances in MCDM Models, Algorithms, Theory, and Applications*
Fox, B.L. / *STRATEGIES FOR QUASI-MONTE CARLO*
Hall, R.W. / *HANDBOOK OF TRANSPORTATION SCIENCE*
Grassman, W.K. / *COMPUTATIONAL PROBABILITY*
Pomerol, J-C. & Barba-Romero, S. / *MULTICRITERION DECISION IN MANAGEMENT*
Axsäter, S. / *INVENTORY CONTROL*
Wolkowicz, H., Saigal, R., & Vandenberghe, L. / *HANDBOOK OF SEMI-DEFINITE PROGRAMMING: Theory, Algorithms, and Applications*
Hobbs, B.F. & Meier, P. / *ENERGY DECISIONS AND THE ENVIRONMENT: A Guide to the Use of Multicriteria Methods*
Dar-El, E. / *HUMAN LEARNING: From Learning Curves to Learning Organizations*
Armstrong, J.S. / *PRINCIPLES OF FORECASTING: A Handbook for Researchers and Practitioners*

Index