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Some evidence in support for a qualitative approach in decision making - Empirical and theoretical -

A. C. ZIMMER [1]

Summary, Zusammenfassung

The apparent effectivity of processing numerical values on computers combined with the impression of exactness of numerical information explains the prevalence of quantitative approaches to decision making. In two experiments on group-decision making it is shown that using qualitative expressions in communication leads to faster decision processes which - furthermore - take better care of the inherent complexity of the task.

Interpreting decision making as a specific form of problem solving, Toulmin´s model of syllogistic reasoning is taken as a starting point for a model that integrates quantitative and qualitative as well as precise and fuzzy information in the generation of conclusions. The applicability of this model is demonstrated in two areas of marketing research, namely the modeling of interdependencies of market data and the optimization of price setting. A by-product of the latter example is the demonstration that apparently the relation between utility (defined as the propensity to buy) and value (defined as the price) is non-monotonic, a result which emphasizes the necessity for a qualitative approach to decision making.

Key words: fuzzy numbers, group decision making, marketing research, problem solving, qualitative models, syllogistic reasoning

Einige Evidenzien für eine qualitative Entscheidungsforschung

Die offenkundige Mühelosigkeit, mit der speziell seit dem Aufkommen von Computern große Zahlenmengen verarbeitet werden können, verbunden mit dem Eindruck ihrer Exaktheit erklärt, warum quantitative Analysen der Entscheidungsforschung überwiegen. In zwei Experimenten zur Entscheidungsfindung in Gruppen wird gezeigt, daß qualitative Wahrscheinlichkeitsausdrücke in der Kommunikation dazu führen, daß Entscheidungsprozesse schneller durchgeführt werden können und daß diese Entscheidungsprozesse der Komplexität der Aufgabe besser gerecht werden.

Wenn man Entscheiden als eine spezielle Form der Problemlösung betrachtet, bietet es sich an, Toulmins Modell des syllogistischen Schließens dahingehend zu erweitern, daß sowohl quantitative wie auch qualitative, präzise wie auch unscharfe Information bei der Generierung von Schlußfolgerungen berücksichtigt werden. Die Anwendbarkeit dieses Modells wird anhand von zwei Fragestellungen aus dem Bereich der Marktforschung demonstriert, nämlich die Modellierung der Interdependenzen von Marktdaten und die Optimierung der Preisgestaltung. Ein Nebenergebnis des zweiten Beispiels ist der Nachweis, daß offenkundig die Beziehung zwischen Nutzen (definiert als Kaufneigung) und Wert (definiert als Preis) nicht monoton ist; dieses Ergebnis demonstriert die Notwendigkeit für einen qualitativen Zugang zur Entscheidungsforschung.

Schlüsselwörter: unscharfe Zahlen, Entscheidungen in Gruppen, Marktforschung, Problemlösen, qualitative Modelle, syllogistisches Schlußfolgern

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[1] Prof. Dr. Alf Zimmer, Department of Psychology, University of Regensburg, Post Box 397, D-93040 Regensburg, Germany, E-mail: alf.zimmer@psychologie.uni-regensburg.de

The philosophical attitude going back to Descartes, that one should regard as well founded and scientific only those arguments which make use of mathematics, has led to a critical narrowing down of the decision sciences to formal approaches and normative models. Rapoport (1988, p. 123-137) points out the specific problems of an entirely quantitative approach to decision making: The temptation is very strong to express all possible values in numerical form... The attraction of numbers lies in the possibility to arrive at a consensus via qualitative evaluations. It is always possible to decide which of two number is larger... Without any doubt quantification in some areas is inevitable. However, it becomes a trap if applied in a purely formal manner... Quantification becomes a caricature if one combines the utility and the expectation of a negative event which has not had any precedence (Rapoport, 1988, p. 132, translation by the autor).

This subtle rhetorics by numbers has finally led to the situation where the conditions of successful decision making are no longer investigated - especially in complex, that is, realistic situations - but the ´illusions of everyday man´, that is, where the decision maker departs from the normative recipes (see Kahneman, Slovic, Tversky, 1982) and the number of such illusions keeps increasing.

It is apparently necessary to discard this too narrowly defined concept of rationality, because for many real-world situations it is impossible to define the best, that is, the only rational course of action. Additionally it is questionable if generalizations can be made from ´irrationalities´ in simple situations to deviations from rationality in complex situations. The major reason for these problems is that in complex situations a large amount of informative data are processed which do not fit into the framework of quantitative decision making: for instance, the *strong* belief in the reliability of predictions concerning a *moderate* increase of the GNP *justifies* the hiring of *some* people for the production of *medium* priced consumer goods - it would be hard to denounce this justification of action as irrational. Further, if the question of accountability is raised, after this course of action has failed to render the expected profit, would it be rational to charge the CEO with neglect or not? In order to escape these traps, an appropriate qualitative frame-work for real-world decision making is necessary. This frame-work should be one which not only incorporates the different kinds of information - from purely qualitative over vaguely quantified to numerical - but also the argumentative schemata and contexts of justification and accountability.

With the help of two paradigmatic experiments on information exchange and decision making, as well as a case study in marketing, a framework for discourse with fuzzy predicates and for rational decision making will be developed.

Part 1

For a long time it has been well known that verbal expressions referring to quantities are highly informative (see Simpson, 1944, 1963; Cliff, 1959; Howe, 1963; Parducci, 1968; Lichtenstein & Neuman, 1967). More recently, the development of the theory of fuzzy sets (Zadeh, 1963) and especially of the concept of linguistic variables (Zadeh, 1975) has stimulated a lot of experimental investigations into the vague meanings of probability terms (Wallsten, Budescu, Rapoport, Zwick, Forsyth, 1986; Budescu, Weinberg, Wallsten, 1988; Zimmer, 1983). However, only rarely have these results been applied to the social context in which verbal expressions referring to quantitative variables are used; this is excepting the field of medical information for patients (see e.g. Merz, 1991; Merz & Fischhoff 1990) but even here the situation is far from settled (see e.g. Nakao & Axelrod, 1983).

In the field of group decision making there exists a host of studies on the pro and cons of different decision rules (see e.g. Fishburn, 1964), on the dynamics of group processes and the influence of the resulting decisions (see e.g. Janis & Mann, 1977) and on shared mental models (Orasanu, 1994); for the key concepts see MacCrimmon (1980), p. 147.

Table 1: Key concepts for the two person team (mixed interests)

Mixed interests	**Differential resources**
No Communication: non-zero transferability, individual vs. group rationality, knowledge of actions, payoffs, problem types: prisoner dilemma, etc., solution possibilities, metagame, equilibrium, stability, randomization, mutural expectations *Communication:* identification of common interests, gains from exchange, market, bargaining: offers, threats, concessions, social exchange	task differences, allocation, resource specialization, flexibility, different levels, different skills, division of labor, comparative advantage, resource match, synergy, role differences, leadership, agency control over decision variables, payoffs, risk sharing, moral hazard, enforceability, contracts, rules, penalties

The direct observation of the usage of verbal expressions for qualitative terms and the resulting effect of their occurrence on the ease and effectivity of communication have rarely been investigated; an exception is the analysis of air-controller communications by Morrow (1994). For this reason, two paradigmatic experiments have been designed to find out how often and under which conditions verbal expressions for quantitative terms are spontaneously used and how this usage affects the quality of communication and decisions.

The focus in the following two studies is on the communication aspect of group decision making, especially concerning the question of how qualitative information about quantitative variables affects the performance of interdependent operators and groups.

Experiment 1

What happens in control tasks, which involve the interaction of two operators (e.g. pilots), can be regarded as the minimal model for processes in group decision making. Therefore and because of its relevance for industrial settings, especially where hybrid automization (Rasmussen, 1976, 1982; Rasmussen & Goodstein, 1987) is the appropriate form of organization, we start from an analysis of control situations and then, following this perspective, we will expand our investigation towards situations characterized by complex mental models and preplanning.

Figure 1 shows the control task of a single pilot together with the influence of human factors.

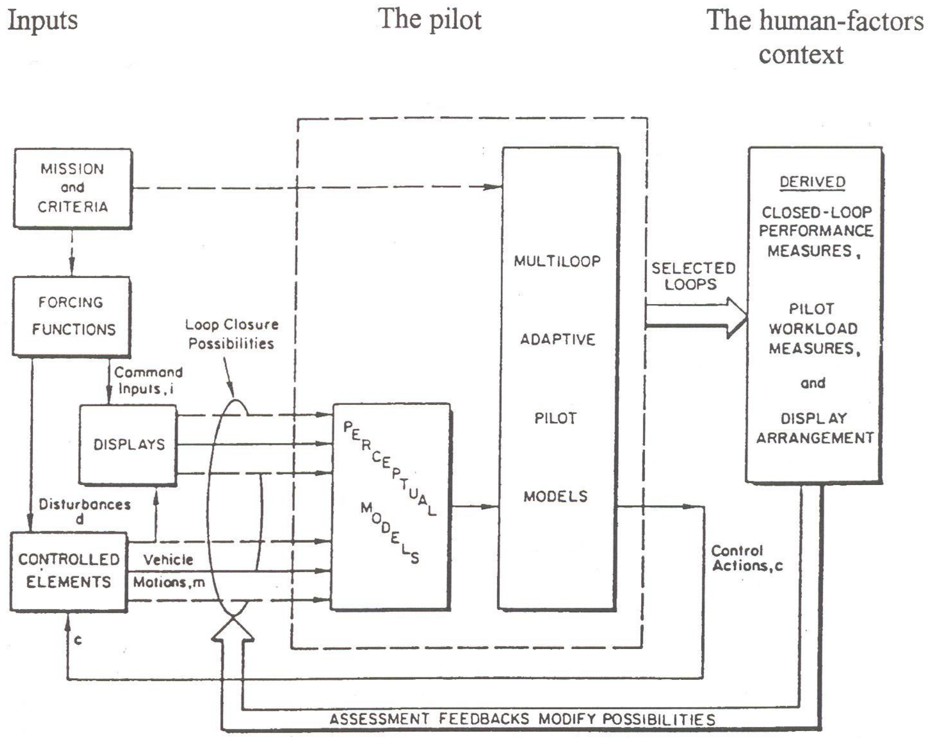

Figure 1:
Human factors in the cockpit for a single-pilot plane (modified after Clement, Jex, Graham, 1968, p. 95).

This control task becomes qualitatively different if, instead of a single pilot, a crew of two or three members is flying the plane. Not only the sheer complexity of two-pilot cockpits, but especially the communication task constitutes this difference. Communications between the pilot and the co-pilot are sometimes highly standardized, e.g. with the help of checklists before starting or landing, however, the question of what the most effective communication for joint control in emergency situations is remain unanswered. The crews in the cockpits of airplanes can be regarded as small groups, thus decision making in this situation has not only to take into account the specifics of individual decision making but also the influence of the communication structure in this group and the specifics of this communication.

Interdependent control tasks like flying a commercial airplane necessitate communication between all those participating in the task. This communication can be either direct in face-to-face situations, indirect or remote and the quality of the communication is decisive for the quality of the control.

The information can be conveyed from one participant to the other, either by giving both access to all available information, for instance, if instrument panels are shared as in the Airbus 320, or by transforming the information into verbal, numerical, or general symbolic messages.

In both cases, commands or instructions make symbolic messages necessary; these can be straightforward and simple as in "set flaps at 15", more complex as in "press button X, until dial Y reaches position Z" or it can be a verbal short-hand instruction relying on a shared frame of reference as in "accelerate slowly" or "keep the pressure in component X low".

In order to be effective, this communication has to be

i) as informative as necessary (not too little but also not too much)
ii) resistent random perturbations (e.g. noise), that is, the meaning should be transmitted without any form of misunderstanding (phonetic or conceptual)
iii) easily and quickly understandable, that is, only a moderate cognitive capacity is needed to process its informational content; in a very few cases the processes can be automatic.

In order to investigate these aspects of cognitive ergonomics for pilots, it must be determined which modes of communication are spontaneously used under different environmental or task conditions. In an experiment with students as mock pilots (64 subjects) we have investigated the communication in a simulated cooperative monitoring task with dials showing numerical values (see Figure 2) under the following conditions and combinations (see Zimmer & Scheuchenpflug 1994):

i) pretraining in the task (A1) vs. no pretraining (A2)
ii) prior acquaintance with the instrumentation (B1) vs. no acquaintance (B2)
iii) face-to-face (C1) vs. remote communication (C2)

The dependent variables are the frequencies of quantitative and of qualitative utterances in the communication.

Only if the subject had no prior acquaintance with the instruments and had to communicate by phone, did the communication consist mostly of explicit and complete numerical messages as read from the instruments. Additionally, subjects who lacked pretraining all only used numerical messages. In all other cases qualitative and short-hand messages prevailed, that is, the numerical information of dial positions of the instrument was transformed into qualitative messages as, for instance, "pressure in component X is high and slightly increasing" and the like.

In combinations (A1, B1, C1) and (A2, B1, C1) numerical data only rarely entered into the utterances. The lack of prior acquaintance and of pre-training both led to an increased number of misunderstood qualitative messages, this was mostly due to different frames of reference for the qualitative messages: slow/fast, high/low etc. (see results in Figure 3).

In contrast, the numerical messages that rely on a general and shared frame of reference, namely the measurement system of physics, do not induce this kind of informational mismatch. However, under speeded conditions, these numerical messages were quite often distorted: Typical errors are e.g. 110° instead of 1100°, especially if spoken as one-one-zero, or permutations if a number consisted of more than 3 digits, (e.g. 5678 instead of 5768 feet).

With increased complexity (process monitoring plus planning of new procedures, e.g. planning an alternative route in order to avoid a thunderstorm) subjects tended to switch entirely to qualitative messages. In the cases without pretraining (A2) and no prior acquaintance (B2) the stress induced sometimes dramatic breakdowns in communication because of the lack of common frames of references (see results in Figure 4). However, remedial training, that is, letting subjects interactively calibrate their qualitative judgments, soon resulted in an improved communication behavior.

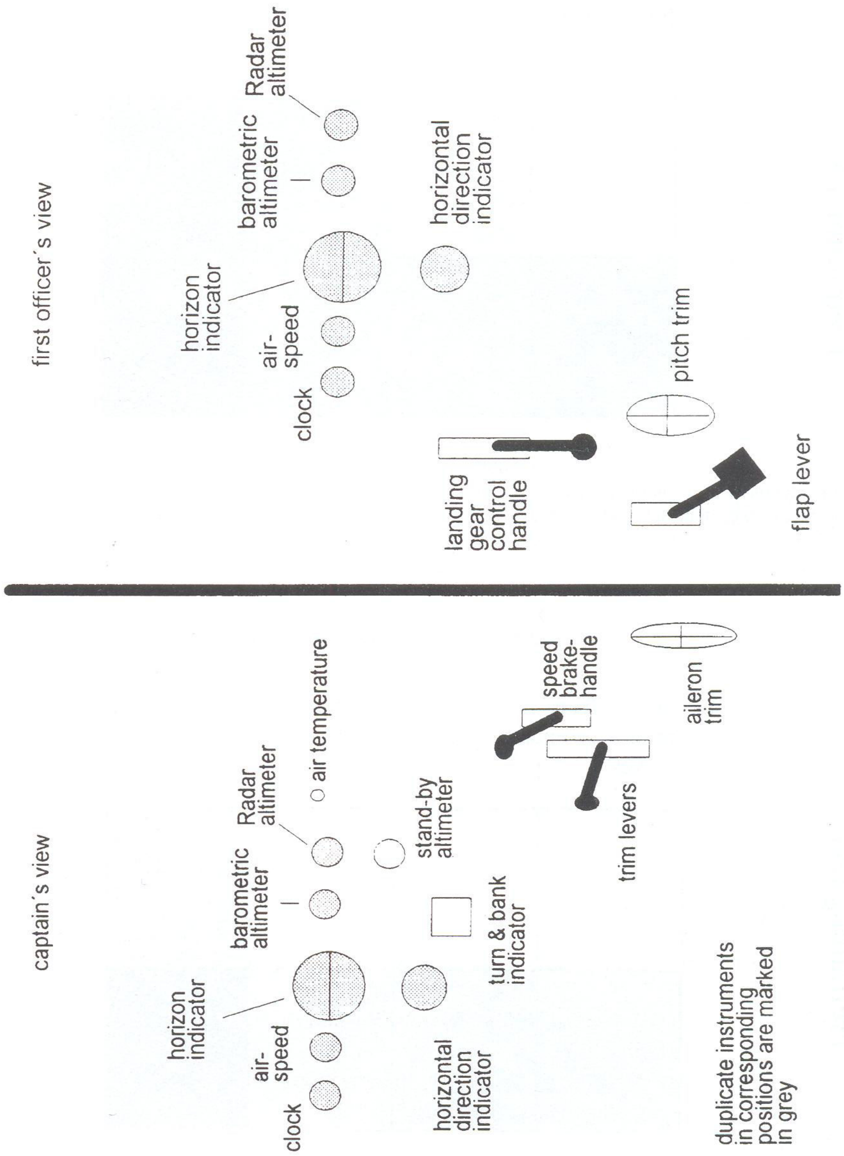

Figure 2:
Mock two-pilot cockpit for Experiment 1

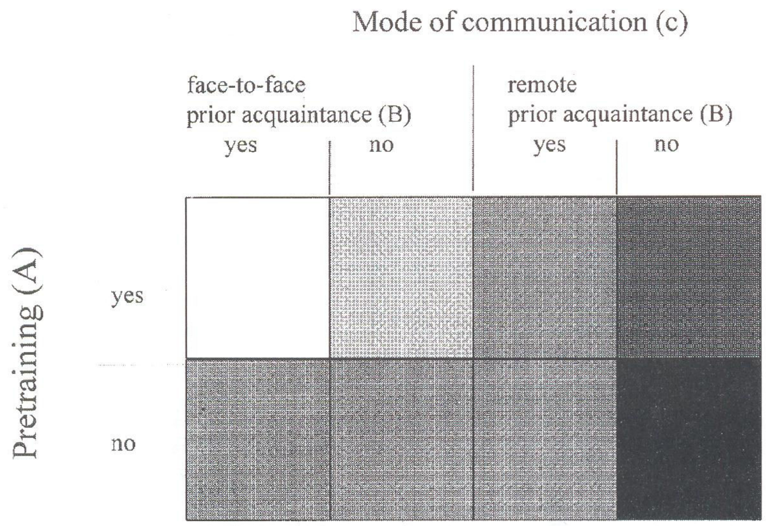

Figure 3:
Percentage of utterances in numerical form; white block: less than 5%; light-grey block: less than 25%; dark-grey block: less than 50%; almost black block: less than 75%; black block more than 90%.

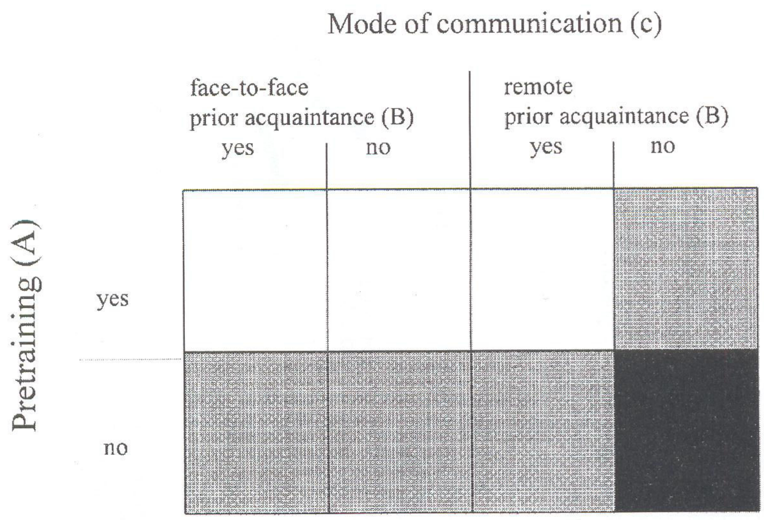

Figure 4:
Percentage of misunderstood utterances under speeded condition with planning and an additional planning task; withe block: less than 10% errors; grey block: less than 25% errors; black block: more than 50% errors.

A more detailed analysis of the meaning of these qualitative utterances has revealed that they can be modelled as operations with fuzzy numbers as in the models suggested by Zwick, Budescu, Wallsten (1988), Oden (1977) or Zimmer (1988). It turns out that such approaches can help to pin down the advantages and disadvantages of spontaneous qualitative communication in the investigated monitoring tasks. At least for pilots who know each other and who have had the same pretraining, verbal communication with qualitative judgments seems to best meet the requirements of cognitive ergonomics, especially if the tasks are complex.

The first experiment so far has highlighted the value of qualitative information in one-to-one or one-to-many situations where - at least for experienced pilots after some training - this mode of communication speeds up the execution of tasks and eliminates errors. In order to investigate the applicability of these preliminary results in more detail it would be desirable to repeat these experiments on *real* pilots with different levels of expertise. Furthermore, the monitoring and operating tasks should be observed either in a variety of real situations or in more complex and more realistic simulations. Finally the interdependence of task specificity and modes of communication has to be analyzed in more detail. A just finished pilot study with pilots in a flight simulator coping with emergency situations has produced comparable results (Hark, 1995).

The results of this in-depth investigation of communication modes in monitoring and operating tasks could make it possible to tailor communication trainings to the demands of the specific tasks.

While the first experiment is mostly concerned with determining under which conditions which mode of communication is spontaneously used, the second experiment addresses explicitly the effect of modes of communication on the quality of decisions which depend on them.

Experiment 2

The second experiment is concerned with the question, how the mode of communication (quantitative vs. qualitative) influences the quality of complex decisions made by groups. The quality of such decisions can be assessed from the number of relevant dimensions taken into account and from the percentage of correct combinations of these dimensions underlying the final decision. For this experiment it would have been interesting to analyze tasks like the allocation of the work force in fleet maintenance or the optimization in flight control. However, for reasons of practicability - we did not have access to enough experts or trainees in these fields - a task of comparable complexity has been designed for a subject domain in which advanced students could be used as experimental subjects.

For this experiment a fairly complex irrigation task has been designed. The groups have to make decisions about the distribution of water for the duration of one week. Relevant dimensions for correct decisions are: differential need of water for different crops, necessity of continuous watering for the crops, number of sluices to be opened, sequence of sluices, unwanted distribution of fertilizers and pesticides by sequential watering of fields with different crops etc.

The information about these dimensions is either provided in the form of qualitative descriptions (e.g. crop X has to be lightly watered quite often, crop Y needs fertilizer M fairly often, pesticide P is slightly harmful for crop Z etc.) or in the respective quantitative form (e.g.

Table 2: Factors varied in Experiment 2

decision rule	Mode of information: quantitative	Mode of information: qualitative
majority	X_{111} ... X_{1110} Y_{111} ... Y_{1110}	X_{121} ... X_{1210} Y_{121} ... Y_{1210}
consensus	X_{211} ... X_{2110} Y_{211} ... Y_{2110}	X_{221} ... X_{2210} Y_{221} ... Y_{2210}

crop X needs 40 gallons of water per acre 3 times per day etc.). The decisions have to be made either using a simple majority rule or by consensus. Twenty-eight students of biology attending a seminar on ecology served as subjects in the experiment with a 2x2 analysis of variance design with 10 repeated measurements in the two dependent variables: X, number of relevant dimensions taken into account, and Y, percentage of correct combinations.

The first result, which makes it necessary to regard all further results with some caution, is that the variance in cell $X_{11.}$ (quantitative information; majority rule) is significantly greater than in that of other cells. Keeping this in mind as a caveat for the interpretation of p(), there is a significant main effect of the modes of communication on the number of relevant dimensions taken into account. Furthermore there is an interaction between the modes of information and the decision rule: The most information is processed if the subjects work towards a consensus with qualitative information. The same pattern is true for Y, the percentage of correct combinations, but the effects are even stronger (see Table 3 and 4 for the mean results).

In a joint MANOVA analysis, ´quality of decision´ has turned out to be the only significant factor; this allows us to sum up the results in the following way:

i) qualitative information about a complex task helps groups to integrate more relevant variables into their final decision;

ii) if the groups are forced to arrive at a consensus this effect is even stronger;

Table 3: Mean number of dimensions regarded in the decisions

Decision rule	Mode of information: quantitative	Mode of information: qualitative
majority	2.1	3.1
consensus	2.4	3.7

Table 4: Mean number of correct combinations

Decision rule	Mode of information: quantitative	Mode of information: qualitative
majority	3.2	4.1
consensus	3.8	7.3

iii) the comparison of the two dependent measures shows that the more complex cognitive processes, that is, the ones combining different dimensions, gain most from the qualitative mode of information representation.

In conclusion, the two experiments indicate that under certain constraints (e.g. familiarity with the task, getting used to qualitative expressions etc.) the usage of linguistic variables instead of numerical variables improves the quality of control tasks, as well as the quality of group decisions. Furthermore, this effect seems to depend on the complexity of the task and on the complexity of the necessary cognitive operations. This is in line with the assumption that qualitative information processing is more effective or economical, because it reduces the continuous problem space into a discontinuous manifold of reference points.

One further, more theory oriented, advantage lies in the turn towards a qualitative version of judgment and choice: It makes it possible to apply the concepts of problem solving to decision making. Therefore, the formal apparatus as developed under the label of ´fuzzy reasoning´ becomes applicable as a unified framework. However, the literature, especially on fuzzy reasoning, but also on fuzzy decision making is abounding. Nonetheless, only in rare exceptions (Zimmer, 1984b) is a connection built between the formal treatment of the topic and the behavioral and cognitive results which experimental psychology provides. The goal of the second part of this article is, for this reason, threefold

(i) to show how especially the concept of a fuzzy linguistic variable can be used in modelling human reasoning and decision making and

(ii) to identify structural relations between reasoning and decision making and to demonstrate how fuzzy set theory and possibility theory can be applied in unifying this up to now diverse field.

(iii) to apply the developed concepts to problems in marketing.

The treatment of these topics will be decidedly paradigmatic, that is, the illustrations for the topics will mostly be taken from ease studies I have done myself not because they are the most sophisticated (for experimental appraoches I would prefer, for instance Wallsten, Budescu, Rapoport, Zwick, Forsyth, 1986) but because they fit best into my line of argument.

Part 2

The rise of psychological investigations of thought processes has debunked the notion of logic as an - albeit normative - theory of human reasoning (for overviews see Nisbett & Ross (1980) or Kahneman, Slovic, Tversky (1982); for a critical evaluation of these results, see Scholz (1983) or Zimmer (1983)). The question, however, if and how formal approaches to reasoning and human reasoning can be brought together, remains open. The approach proposed here is intended to close the gap somewhat by proposing what could be termed an approach to a formal theory of informal reasoning (Zimmer 1984a).

One can regard the formal (or mechanistic) approaches of logic and decision theory as two distinct but equally accepted modes of scientific reasoning. However, especially in the domain of applied science and even more so in everyday reasoning the distinction between these approaches is at the least blurred and in many situations it is even the case that an argument appears only as acceptable if it contains statistical (decision oriented), as well as deductive (logical) elements.

The richness of argumentative structure, which is so salient in everyday reasoning (including the reasoning of experts in the applied realm), is coupled with the well known limitations of this kind of reasoning. For example, it is biased towards confirmation, representativeness, and availability and, further, it is limited in the amount of information (factual as well as formal) that can be processed at the same time. Effective support systems must therefore have a rich structure, which is able to mirror the expert knowledge, but at the same time they must also have the unequivocality and processing power of mechanical approaches. The goal of the following will be to sketch a framework for such a system and to give an example of where it has been applied in marketing.

A schema for reasoning and argumentation

In order to more clearly specify the intended goal of such an approach, it seems appropriate to compare 'classical' formal approaches, that is, predicate calculus and probability theory, with what is known about everyday reasoning. In Table 5 the positions of predicate calculus, probability theory, and everyday reasoning regarding central problems of reasoning are compared.

The inspection of Table 5 highlights the fact that, in general, predicate calculus and probability theory take very similar approaches towards problems and modes of reasoning despite their different structure. Exceptions, however, are the evaluation of partial or circumstantial evidence and the weighing of evidence by probabilities or by diverse colloquial qualifiers; here probability theory and everyday reasoning take similar positions. What distinguishes these points from the rest of Table 5? They apply to situations where only approximate solutions are possible, where the reasoning does not lead to the "true/false" alternative, but to a case where only degrees of plausibility or veridicality can be reached.

As Toulmin (1964) observes, standard logic has been developed with an eye on mathematics where such ambiguous situations are to be avoided at nearly any cost (but see, for instance, Kline 1980). In order to liberate logic from this Procrustean bed, Toulmin suggests the reconstruction of logic according to the model of legal argumentation. He suggests a scheme of syllogistic reasoning with the following components:

Table 5: Comparison of models of reasoning

	Predicate Calculus	**Probability Theory**	**Everyday Reasoning**
law of the excluded middle	*valid* without specification	*valid* in the definition of the event space	*usually not valid* except for easily enumerable ensembles
Modes of reasoning: **- deduction**	*valid* without exception	*valid* without exception	*valid* but the result looses plausibility with the length of the deductive chain
- induction	*not valid*	*not valid* in classical approaches (v. Mises, Popper) valid with restrictions in non-standard approaches	*valid* if many convincing analogies can be brought forward
evaluation of partial or circumstantial evidence	*not possible* except for non-standard approaches (non-monotonic reasoning, default reasoning)	*possible* by means of Bayesian or information theoretic schemes	*possible but biased* because of heuristics and/or characteristics of memory (primacy and recency)
use of qualifiers	only standard quantifiers (all, some, not all, none)	not defined except for weighing by probability	without restrictions

(i) *claims:* propositions that are supposed to be true or to be at least plausible to a certain degree
(ii) *grounds:* reasons for believing the claims to be valid (the usual form is that of explicitly or implicitly quantified statements)
(iii) *warrants:* statements about the relations between grounds and claims (e.g. causality, necessity, sufficiency, contingency)
(iv) *backing:* commonly shared knowledge (Smith 1982) which provides the rules for a combination of grounds and warrants in order to justify the claims (e.g. rules of syllogistic reasoning or statistical inference)
(v) *modal qualifications:* general quantifiers and uncertainty expressions, for instance, possibly, usually, or necessarily. They apply to the propositions and to the inferential process.
(vi) *rebuttals,* that is, alternative claims which can also be inferred from the grounds, warrants, and the backing, because of the modal quantification of propositions and inferential rules. Rebuttals can be overcome by, either showing that they imply a smaller set of consistent propositions than the claim, or by comparing the overall modal qualification of the rebuttals with the evaluation of the claims.

These components are combined as shown in Figure 5 (Toulmin 1964, p. 104; the figure has been slightly changed in order to avoid inconsistencies).

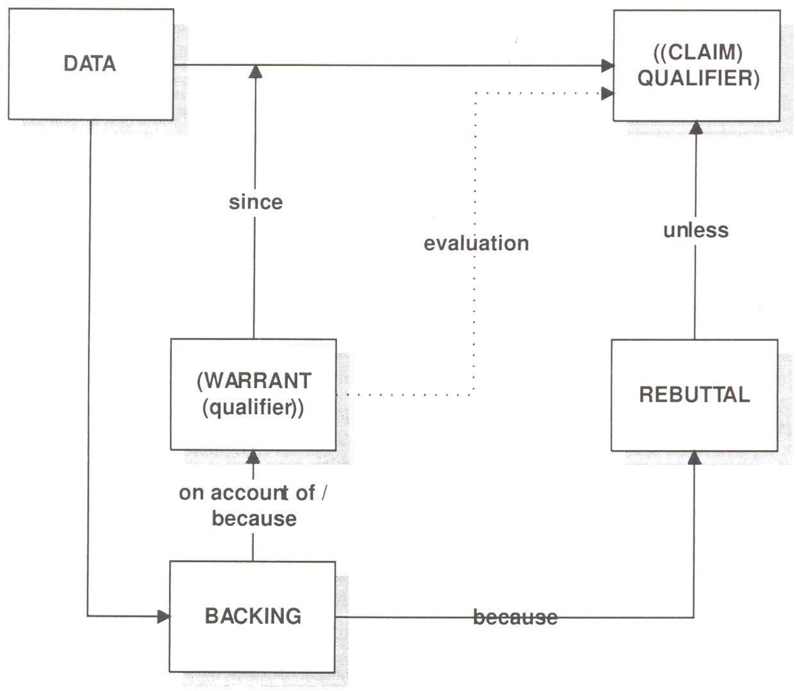

Figure 5:
A modified version of Toulmin's (1964) model for syllogisms in argumentation. Toulmin's original model is indicated by upper case letters and bold lines (Zimmer, 1988)

An example for this kind of syllogistic reasoning by means of analyzing chains of arguments would be the determination of a probable price for a used book (see Figure 6).

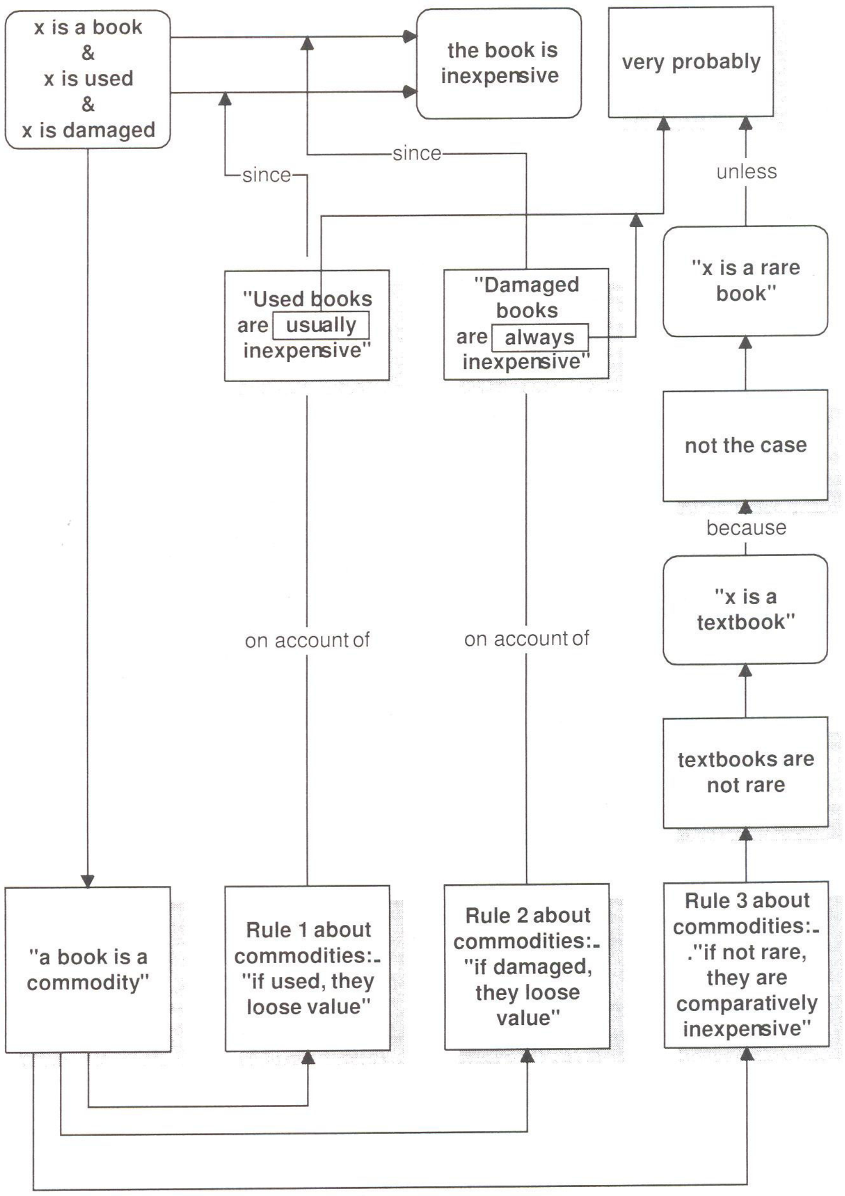

Figure 6:
An application of the modified Toulmin model (Zimmer, 1988)

Figure 6 especially reveals the importance of quantifiers, implicit (denoted by ...) or explicit (usually, always etc.), for the evaluation (qualification) of the claim. In order to develop a formalized version of Toulmin's approach to plausible reasoning, it is necessary to develop a common framework for the interpretation of explicit and implicit quantifiers and furthermore an algorithm for their concatenation.

Fuzzy numbers and qualifiers

The meaning of quantities like "about 50 %" or "slightly below 0.3" (Smithson, 1987) and the addition of "about 50 %" and "a bit more than 10 %" with the result "probably somewhat more than 60 %" seem to make sense immediately. Zadeh (1983) has suggested the interpretation of quantifiers as fuzzy numbers in the [0,1] interval and the use of the operations for fuzzy numbers (Dubois & Prade 1980) as the algorithm for their concatenation. However, it is not clear how the intuitive meaning of imprecise numbers is reflected in the formal definitions of fuzzy numbers and their rules of concatenation (Dubois & Prade, 1980). The formal definitions allow for the proving of abstract theorems in fuzzy number theory and for checks of consistency but they do not provide any guidelines for the mapping of imprecise observable quantities into the different types of fuzzy numbers (_, s, z, s/z, or z\s numbers) or for the setting of parameters. On the other hand, Smithson's (1987) and others´ purely empirical approach of characterizing a fuzzy number by a listing of relative frequencies is not sufficient either, because it does not lead to empirically testable rules for the concatenation of these numbers. Such rules, however, can be derived from results of approximate calculation in the areas of foreign exchange (Zimmer, 1984 b). For merely illustrative purposes, let us start with fuzzy numbers of the form "standard number + qualification" (e.g. "approximately .7"). Figure 7 represents this fuzzy number where the 'core', that is, .7, and the fuzzy upper and lower boundaries, that is, the fuzziness due to the qualification, can be discriminated. The fuzzy number can now be represented by the following triple: lower boundary relative to the core, core, upper boundary relative to the core (.1/0.7, 0.7, .15/0.7).

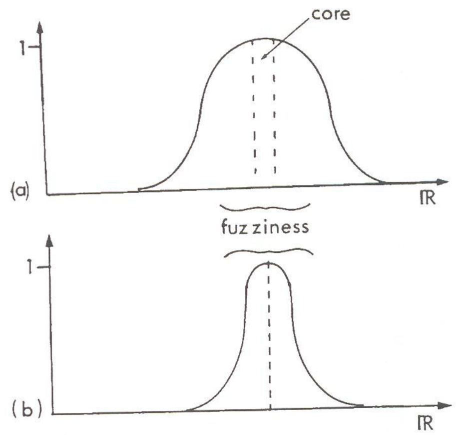

Figure 7:
Fuzzy numbers consisting of a core (or prototypical) meaning of 0.7 and fuzzy upper and lower boundaries. (a) is a fuzzy number with core interval, (b) is a fuzzy number with a point-wise core.

Any two fuzzy numbers can be concatenated by following these steps: (i) calculate the resulting core by means of standard arithmetics, by (ii) averaging the respective upper and lower boundaries, and (iii) determine the resulting boundaries from the averaged boundaries in relation to the resulting core.

The operations with fuzzy numbers corresponding to the standard operations in arithmetics are illustrated in Figure 8a-d.

The described approach of handling the core and the fuzziness separately has been backed empirically, that is, the think-aloud protocols of the subjects reflect this procedure. For fuzzy numbers like 'several', 'most', or 'likely' the same procedure can be applied provided the core has been determined empirically.

Fuzzy arithmetics as a model for reasoning

Starting with the experimental studies by Zimmer (1982, 1984 a and b) empirical evidence has been amassed for Yager's (1980) and Zadeh's (1983 a,b, 1984) claim that fuzzy numbers can be used for the representation of generalized quantifiers (Barwise & Cooper 1981, Peterson 1979) and furthermore that human reasoning with these quantifiers can be modelled according to the operations with fuzzy numbers. As noted above, further experimental studies have led to modifications in the definition of fuzzy numbers as well as of operations with them. These modifications, however, are not crucial for the general claim.

From a formal point of view, quantifiers expressed as fuzzy numbers in the interval [0,1] and uncertainty expressions, represented as fuzzy probabilities are comparable. Furthermore, in chains of argumentation (see Figure 6) both kinds of qualification can be found and should therefore be represented in a common framework for the use in intelligent systems e.g. expert systems (Zadeh 1983 c). Empirical analyses of uncertainty expressions (Zimmer 1983, 1986 a;

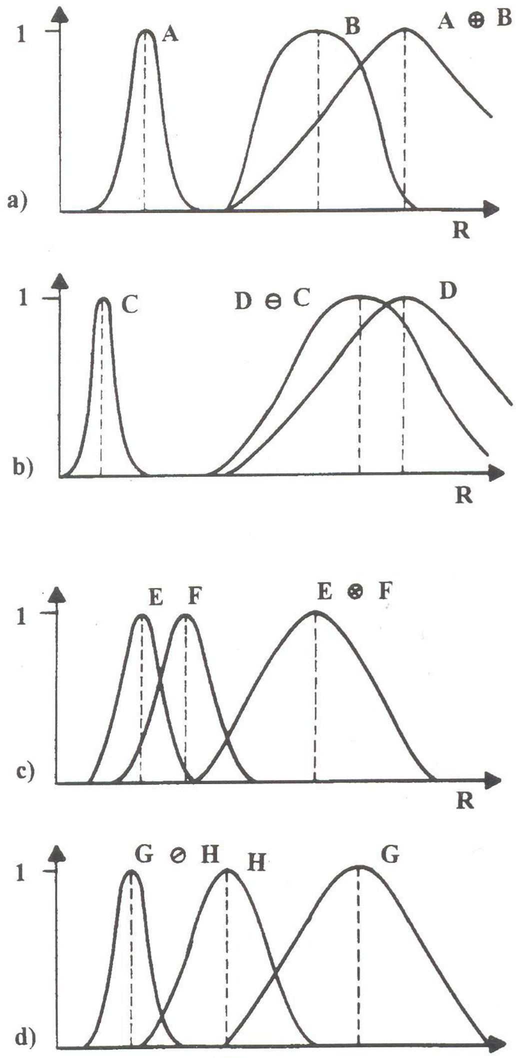

Figure 4

Operations with fuzzy numbers
a/ fuzzy addition ⊕
b/ fuzzy multiplication ○
c/ fuzzy substration ○
d/ Fuzzy division ⊖

Figure 8: Operations with fuzzy numbers

Wallsten, Budescu, Rapoport, Zwick, Forsyth, 1986; and Zwick & Wallsten, 1987) have consistently shown that verbal expressions like probable, likely, or toss-up can be expressed as fuzzy numbers. Different experimental techniques (e.g. pair comparison vs. staircase estimation), different forms of displays (e.g. circle segments vs. random dots), and different samples of uncertainty expressions (all expressions of a language community vs. only those expressions that a subject has in his/her personal active vocabulary) have led to seemingly conflicting results about the consistency of estimates and therefore the applicability of verbal expressions of uncertainty in decision support or expert systems. There are two solutions to this problem: One consists of the Wallsten et al. approach (1986), that is, determining the fuzzy numbers for a complete lexicon of expressions of uncertainty. This leads to *averaged meanings* that can be assumed to be valid for an entire language community. By means of iterative methods (Zimmer 1986 b), ambiguous meanings (fuzzy numbers with more than one peak) can be resolved. The problem with this approach is that the individual's lexicon of uncertainty expressions might differ from that of the language community. The important advantage of this approach, however, is its generality. The other solution for the problem consists in concentrating on the *individual's* lexicon of uncertainty expressions.

Calibrating individual vocabularies of uncertainty expressions by means of staircase methods with random-dot displays Zimmer & Körndle (1987) has resulted in fuzzy numbers that can be represented by (i) single-peaked membership functions, (ii) of comparable shape and (iii) with the tendency towards a proportional relation between the value of the core and the fuzziness. To be more precise, in contrast to fuzzy numbers without interval bounds, the fuzziness in the closed interval [0,1] is relative to the smaller distance of each core from the upper or lower limit. These qualitative aspects of the fuzzy numbers are consistent with the model described in part 2 above. It should be kept in mind that (iii) contradicts one of the theoretical assumptions of Zimmer (1982) and (1983), namely the assumption of equal informativeness on the entire scale of judgment, and therefore equal fuzziness for all expressions of uncertainty in an individual´s active vocabulary. However, the consequence of the unequal informativeness (low in the central part and high in the extremes) is in accordance to the results reported by Wallsten and his group (Wallsten et al. 1986).

The major disadvantage of this individualistic approach, namely its lack of generality, can be overcome by the procedure described in Zimmer (1986 b). It starts with the individual's expressions but maps them into the general lexicon. If the mapping does not result in a single-peaked fuzzy number or if the fuzziness is excessive, it is iteratively searched for the non-degenerate expression which captures best the initially intended meaning (see Figure 9).

During and as a result of the interaction with this computer-controlled procedure, subjects learn to use only those expressions that have a meaning, which is in accordance with that of the language community. However, it restricts the expressive power of the individual lexicon.

The common framework for quantifiers and uncertainty expressions as established by the assignment of fuzzy numbers in [0,1] has to be complemented by a comparison of the algorithms of inference. The standard algorithms, that is, syllogistic resolution and Bayesian weighing of evidence are seemingly incomparable but since Zadeh (1983a) has shown that any form of syllogistic resolution can be modelled by fuzzy quantifiers and fuzzy operators (addition, multiplication, and conjunction), it is possible to use the same operators for Bayesian inference. There is only one additional operator necessary, namely division, for working with conditional probabilities. At first glance, this operator does not fit into the reasoning with quantifiers. However, as Hörmann (1983) and Zimmer (1986a) have shown, in the colloquial

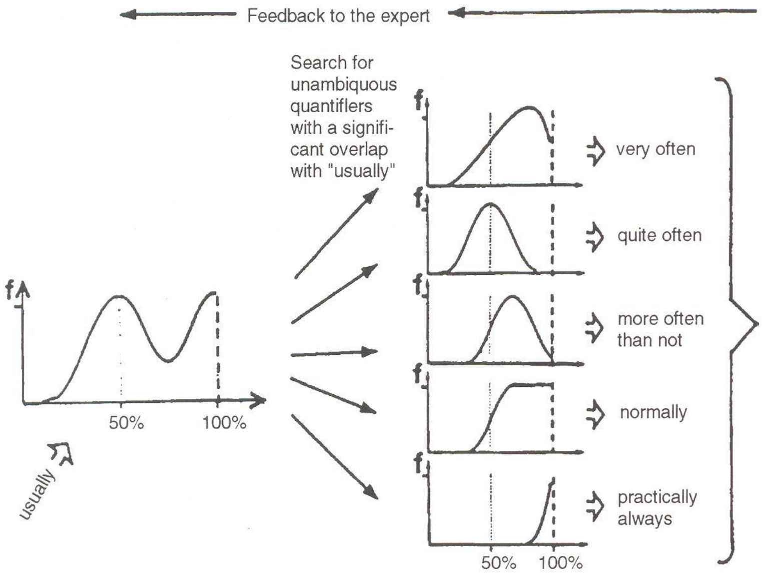

Figure 9:
The interactive determination of unambiguous expressions of uncertainty (Zimmer 1986b)

usage of quantifiers these are quite often conditioned based on the background knowledge about the situation. For instance, the utterance "many of the convertibles" can only be properly modelled if the general meaning of 'many' is taken into account as well as the fact that convertibles form a very small subset of all cars. The implicit reasoning runs as follows: if the cars in question are convertibles, then even a small proportion of all cars fulfills the condition of applying "many". This construction of a conditional quantifier is completely compatible with the notion of conditional probabilities. Using this result, it is now possible not only to assign fuzzy numbers to the qualifiers in Toulmin's model (Figure 5 and 6) but also to interpret the arrows and their combination as fuzzy evaluations of operators (e.g. means fuzzy multiplication). Furthermore, the relations between the backing and the warrants becomes straightforward fuzzy arithmetics.

Application of the model in market research

The applicability of the developed model of reasoning with fuzzy qualification has been tested in the field of market research. A leading German producer of snacks and cereals monitors the distribution and the sale of its products by means of data provided by three different panels.

The *trade panel* estimates parameters for the turn-over in supermarkets and other outlets.

The *household panel* describes the buying behavior of a typical German family by asking 500 families to keep diaries of their buying acts.

Finally, the *insertion panel* monitors advertisements and determines how often a product is advertised and what price is asked for it.

Using these data for controlling the production and the marketing activities is difficult simply because of the amount of data. In cooperation with marketing specialists we have developed a simple constraining net for the parameters in question (see Fig. 10). This constraining net has been integrated into the reasoning model by using it as the BACKING for the CLAIM. By using the input of the actual estimates from the panels as DATA it has been possible not only to link the effects of marketing campaigns (e.g. rebates or promotional activities in advertising) to the general turn-over and to the final gains, but also to take into account link internal data concerning production, purchase of raw material, price of re-providing etc.

In the original study these results were only used as an intelligent assistent system for the market researcher. In a follow-up study we applied this model to the question of optimal price-setting for a German coffee-maker.

By applying this model it was possible to improve the prediction of the general turn-over to $r = .75$ as compared to the prediction using linear regression with a correlation coefficient of $r = .25$, that is, increasing the explained variance by a factor of 9. However, a closer inspection of the different slopes of the regression in different price domains (see Figure 12 a and b) reveals that even such a seemingly continuous scale like the value of money is discontinuous at certain reference points (see Rosch, 1975) and therefore necessitates a qualitative approach.

A further possible application of this kind of combination of expert knowledge (WARRANT and BACKING) and DATA would be to do what-if analyses. By simulating the effects of marketing activities these analyses can be fine-tuned to the overall goals of the corporation or to the expected economic side conditions by choosing a specific strategy, for instance, MINIMAX, MAXIMIN, or the maximization of the expected value or minimization of regret. Thus far, the proposed model addresses exactly what Bernstein (1996) shows to be the critical questions in risk management (see Introduction); it especially allows for the handling of discontinuities, about which Bernstein (1996, p. 51) notes: "And it surely is naive to define discontinuity as anomaly instead of as normality; only the shape and the timing of the disturbances are hidden from us, not their inevitability."

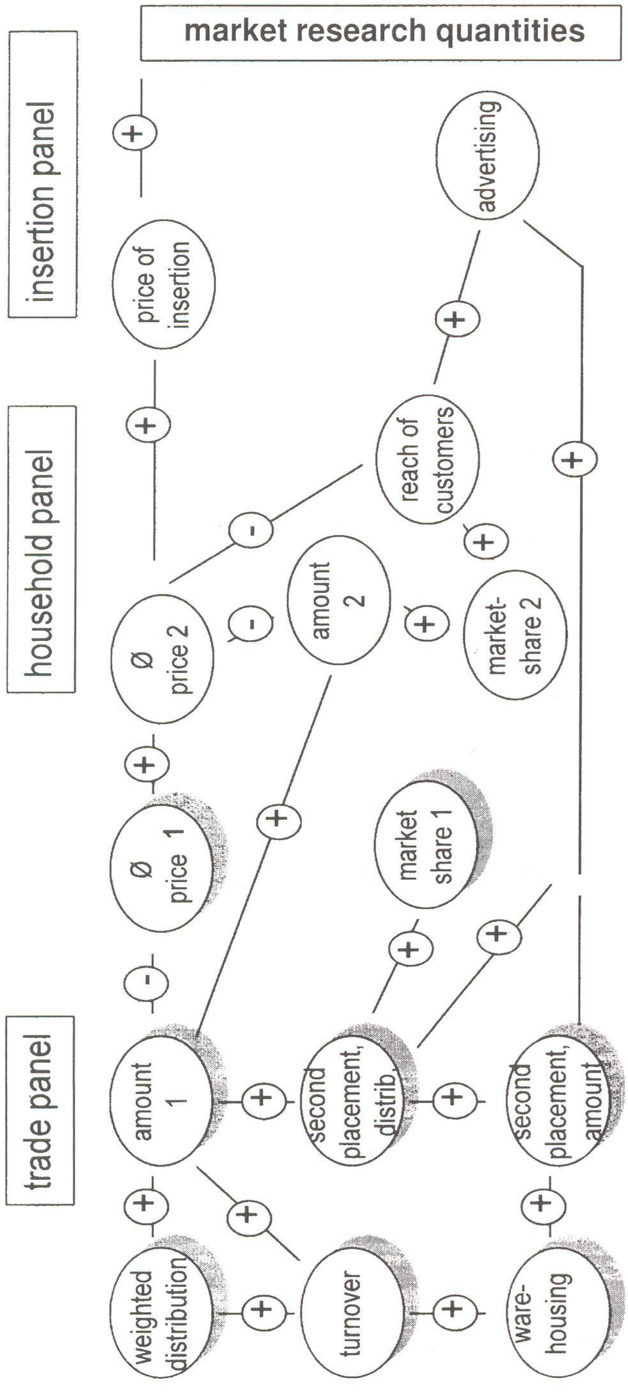

Figure 10:
Constraining net for data from marketing-research panels

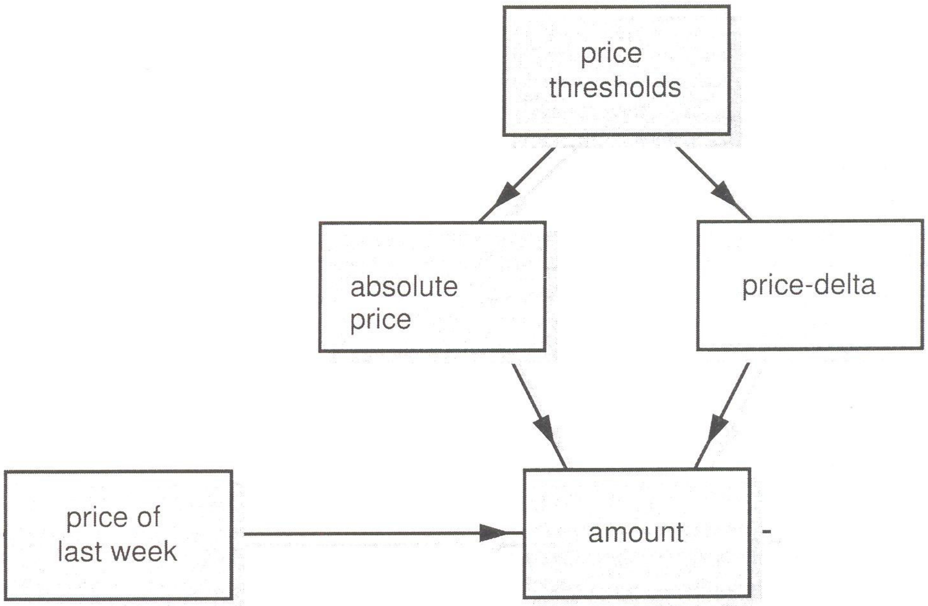

Figure 11:
Inference net underlying optimized price setting

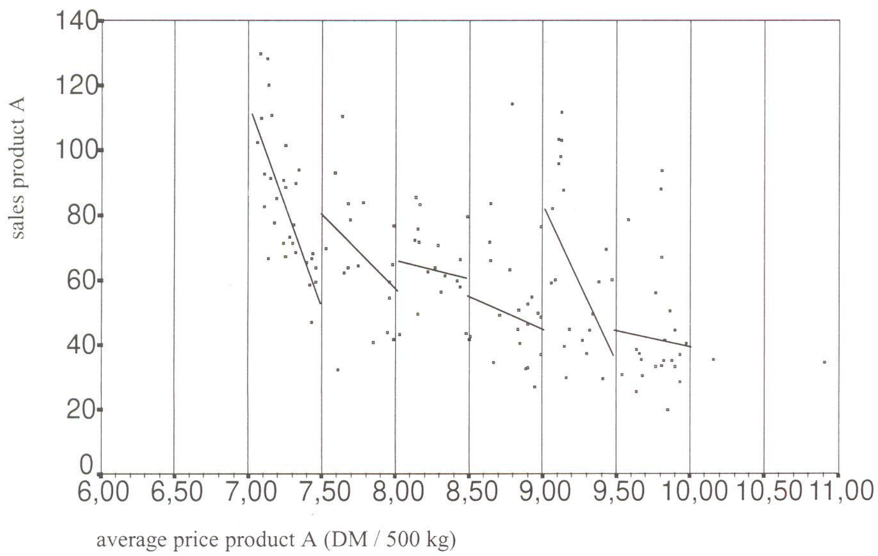

Figure 12a: How slopes of the sales-price regression depend on reference points for prices (Product A)

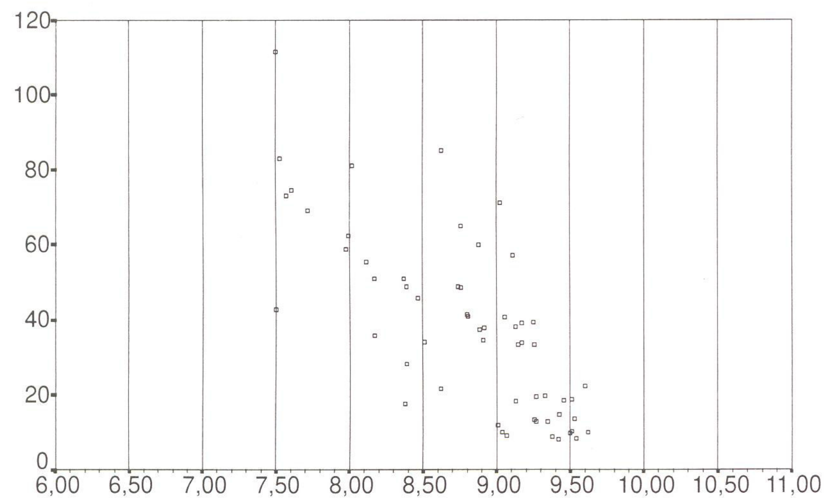

Figure 12b: How slopes of the sales-price regression depend on reference points for prices (Product B).

Figure 12:
a) How slopes of the sales-price regression depend on reference points for prices (Product A).
b) How slopes of the sales-price regression depend on reference points for prices (Product B).

Conclusions and possible expansions

The developed common framework for the two major kinds of information processing, namely decision making and reasoning, allows for modelling intricate nets of arguments by means of fuzzy arithmetics. It seems especially applicable to the development of decision support systems for marketing because in that setting the combination of decision making and reasoning is required.

The model developed so far applies only to *deductive* sequences of or constraining nets for reasoning or argumentation. However, in many forms of discourse other non-deductive rules of inference are used, especially induction and abduction. Induction always applies when general rules are generated from observed instances and specific rules (minor premise) this is not only the case in the scientific domain but also in everyday exchanges. For instance, the message 'dials b, g, h, and p are in the red zone' at the same time should trigger the inductive inference that valve z is blocked and an emergency action is necessary. For abduction that is, inferring a specific rule from an empirical observation and a general rule (major premise), the situation is similar. If I know that alarm signals use the colour red then the observation of a red blinking light allows the abductive inference that an alarm is given. The modified Toulmin schema for reasoning can easily be accomodated for induction and abduction (see Figures 13 und 14). A comparison of models schema in Figure 6 shows that only the direction of arrows has changed, that is, the aim of argumentation is no longer the claim but the warrant or the backing.

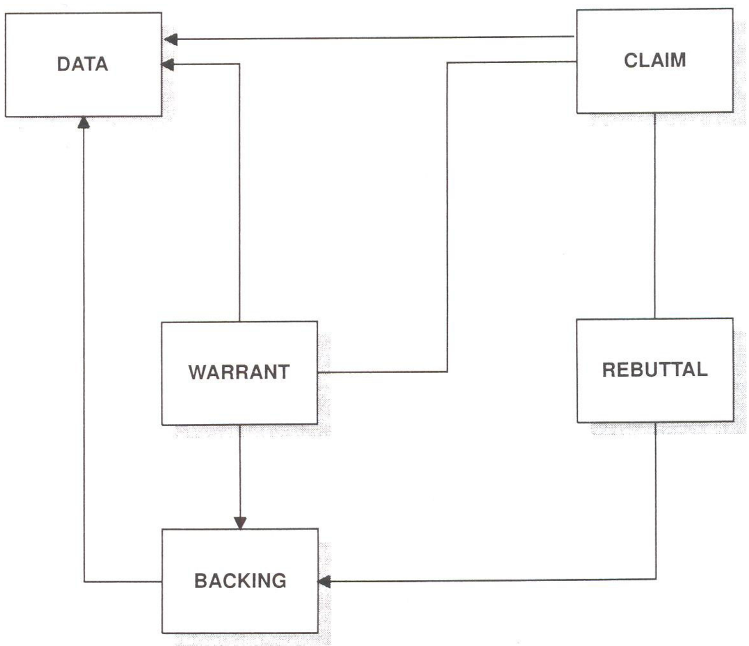

Figure 13:
The Toulmin schema applied to induction

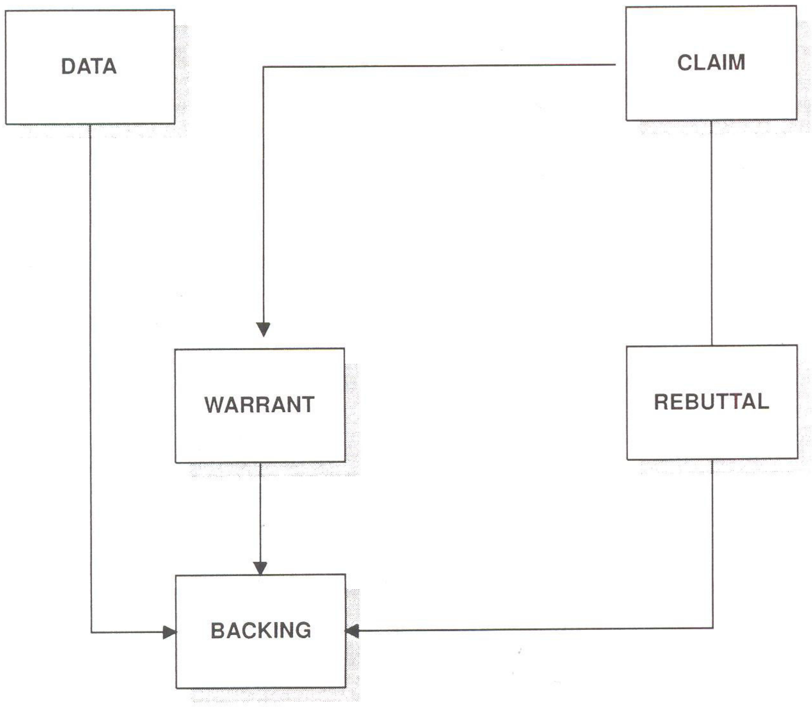

Figure 14:
The Toulmin schema applied to abduction

What makes the analysis of these modes of reasoning especially worthwhile is not only the fact that these modes are applied in everyday discourse, but also that their analysis sheds light on what has been termed heuristics or cognitive illusions.

Tversky & Kahneman (1972, 1974) have developed the heuristics of availability and representativeness for judgments under uncertainty on the background of the psychology of memory, that is, they have turned around the normal chain of arguments by using the results from memory research as their premises for inferences about the glaring contradictions between what is said about situations and what is true about them. From the empirical observation that, what is learned often, becomes especially well retrievable, stems the availability heuristic: *If something comes especially fast to your mind, then you have observed it very often.* On the other hand, from the tendency to accomodate the content of memory to underlying schemata (Bartlett, 1932), to prototypes (Rosch, 1978) or generally to a more regular form (Wulff, 1922), stems the representative heuristic: *Most objects and events of our world can be classified into comparably few categories from which they differ only randomly, therefore an observation which resembles the underlying category especially well has a high probability of occurring.*

What is implicitly assumed in this approach is that folk psychology (Stich, 1983) provides people with a model of their own memory according to which they *know* something about the laws underlying association and the laws underlying classification, that is, they carry with them an Aristotelian view of classification and not only one of physics (McCloskey, 1983). The Aristotelian flavour of cognition in folk psychology becomes even more apparent if one inspects the modes of inference people use when they apply these heuristics. In his Analytica Prima (II, 25,69a) Aristotle describes abduction, a mode of inference where the major is certain and the minor is uncertain but both are at least as believable as the conclusion; defined this way, abduction is a kind of probabilistic inference. Charles S. Peirce (1878) has systematized the inference processes underlying the posing of hypotheses. He distinguishes between abduction, where a hypothesis about the *case* is generated from a *general rule* and a specific observation (*result)* and induction, where a hypothesis about a *general rule* is generated from a *case* and a specific observation (*result*). The relationship between abduction and induction on the one hand, and availability and representativeness on the other hand, becomes especially apparent if one analyzes the following examples:

1. Abduction
rule: All engineers have a training in mathematics and are interested in technology
result: Mr. X has a training in mathematics and is interested in technology
case: Mr. X is an engineer

2. Induction
case: Mr. X is an engineer
result: Mr. X has a training in mathematics and is interested in science fiction
rule: Engineers have a training in mathematics and are interested in science fiction
or
case: This is a poll from Bavaria
result: The tendency in this poll favours conservative positions
rule: Bavarians favour conservative positions.

In my opinion, these examples show convincingly that behind the cognitive heuristics of availability and representativeness, the cognitive processes of hypothesis formation, as described by Charles S. Peirce under the terms abduction and induction can be identified. In the context of decision making these heuristics become cognitive illusions, not because the cognitive processes behind them are inherently biased, but because the generated hypotheses are not tested. They are taken at face value, meaning that, in the hypothetico-deductive loop negative feedback is lacking.

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