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A methodology for knowledge acquisition through literature: Building knowledge-based systems for strategic management

Manuskripte aus den Instituten für Betriebswirtschaftslehre der Universität Kiel, No. 279

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Suggested Citation: Lehmann, Andreas (1991) : A methodology for knowledge acquisition through literature: Building knowledge-based systems for strategic management, Manuskripte aus den Instituten für Betriebswirtschaftslehre der Universität Kiel, No. 279, Universität Kiel, Institut für Betriebswirtschaftslehre, Kiel

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No. 279

A Methodology for Knowledge Acquisition
through Literature

- Building Knowledge-Based Systems for Strategic Management -

Andreas Lehmann

↳

November 1991

*Based on a paper presented at the
«European Summer School on Management of Technology».
University of Kiel, Germany, August 18 to August 31, 1991.*

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1. Introduction

Decision making in strategic management requires information as well as adequate models in the problem solving process. Information in this domain is qualitative rather than quantitative, problems are usually ill-structured¹ and often are solved through heuristics.² Whereas traditional decision support systems (DSS) mostly handle quantitative information and models, knowledge-based systems (KBS) or expert systems, a branch of artificial intelligence, offer capabilities to use qualitative information and heuristics in the problem solving process. Therefore, a KBS offers a great capacity for supporting problems in the domain of strategic management.³

The traditional method of building a KBS is to elicit knowledge from human experts.⁴ Applying this approach to the process of knowledge acquisition requires time consuming and cost intensive sessions. However, human experts are only one possible source of domain specific knowledge. A great amount of knowledge is stored separately from these experts, in databases, protocols, or generally in literature.⁵

While in the research of developing a KBS considerable emphasis is laid on methodologies how to elicit knowledge from a human expert (e. g. by interviewing) already existing data is not extensively used to build knowledge bases. A lack of appropriate methodologies for transforming existing knowledge into a KBS has to be recognized.

In projects that use textbooks for knowledge acquisition the transformation process of the relevant text into a formalized knowledge base appears uncritical or not transparent. Research in artificial intelligence emphasizes technical problems rather than problems arising from interpretation and degree of reliability of the information.

To sum up, one must recognize the importance of information in business decision making as well as the lack of methodologies using already existing knowledge appropriately in decision support systems. Literature of a special domain usually contains a large volume of information and should be considered extensively in the development of a knowledge base. Despite that importance, this topic has attracted little discussion or research.

This paper presents a methodology showing how information, stored in literature, can be transformed into the knowledge base of a KBS. The process of knowledge acquisition is systemized and the content of the knowledge base is made transparent; knowledge

¹ E. g.: Ansoff (1976) and Mintzberg, Raisinghani, Theoret (1976).

² E. g.: Rowe, Somers, Schutt (1988), p. 60.

³ E. g.: Mockler, Dologite (1988), Orsini (1986) and Luconi, Malone, Morton (1986).

⁴ Most of the knowledge acquisition methods discussed in the literature refer to human experts as source of knowledge. An overview of these methods is given in: Reitman, Rueter (1987).

⁵ Marchant (1990), p. 62.

expressed in natural language is formalized into a rule-based KBS. This methodology is applied in the field of strategic management, therefore some aspects discussed within this paper concern this field. However, the methodology presented can be applied in other fields with similar characteristics as well.

2. Knowledge acquisition

2.1. Definition and general requirements

Knowledge acquisition can be defined as the process by which expert system developers find the knowledge that domain experts use to perform the task of interest.⁶

A more extensive definition by Breuker and Wielinga⁷ describes knowledge acquisition as the methodology for the formation of a model on expertise, so that this model can be used as a basis for a design specification (design model) and subsequent top-down implementation of an expert or knowledge-based system.

This process can mainly be subdivided in the activities knowledge elicitation, data analysis and domain conceptualization.⁸

In both of these definitions the selection of the domain is a process done beforehand, and the implementation and testing or evaluation are processes occurring after knowledge acquisition.⁹ The kernel of this process can be described as «knowledge elicitation» i. e. getting the relevant knowledge from experts or, as in our case, out of texts.

In general, knowledge acquisition is a dynamic process, knowledge in specific domains is changing constantly. This phenomenon has to be considered and knowledge bases have to be updated periodically in order to maintain their worth in supporting decision making.

In order to obtain a knowledge base that supports decision making in the domain of interest, the knowledge acquisition process has to meet several requirements:

- Completeness of relevant data (quantity).
- Correctness and Reliability of knowledge (quality).
- Consistency of knowledge and model.¹⁰
- No modification of the original knowledge through the knowledge acquisition process.
- Comprehensiveness and transparency of knowledge base.

The subsequent presented methodology has to consider these requirements.

⁶ Prerau (1990), p. 200.

⁷ Breuker, Wielinga (1989).

⁸ Rajan, Motta, Eisenstadt (1988), p. 113.

⁹ Similar phases are suggested by Woodward (1990), p. 74.

¹⁰ The first three criteria are also mentioned in: Swaby (1990), p. 216.

2.2. Classifications

A great variety of methods have been developed for knowledge acquisition. Possible classifications of these methods are given, with the more important methods mentioned explicitly.

Reitman and Rueter¹¹ give an overview of several methods for knowledge acquisition. They distinguish between **direct** methods in which the expert articulates his knowledge directly, and **indirect** methods in which the behavior of the expert is observed, from this it is deduced what the expert must have known. Direct methods would be interviews, questionnaires, simple observation and thinking-out loud protocols. Indirect methods, for example, include multi-dimensional scaling or hierarchical clustering.

This classification has one substantial shortcoming; it does not include methods used for knowledge acquisition through existing knowledge bases, especially through literature.

Another classification of knowledge acquisition methodologies is to distinguish between **case-based** and **model-based**¹² knowledge acquisition, depending on the underlying characteristics of the data that is transformed into the knowledge base. In the case-based method a number of cases is studied where the expert or the decision maker has drawn specific conclusions. The underlying rules used by the expert in this cases can be inferred by applying learning procedures.¹³ In this sense case-based knowledge acquisition can be described as indirect method. The model-based knowledge acquisition, in contrast, is more a direct knowledge acquisition, in that formulations or rules from experts or in texts directly are transformed into the representation form of the knowledge base. Literature can contain both knowledge for model-based as well as for case-based knowledge acquisition.

The origin of the knowledge can serve as another criterion by which to classify the knowledge acquisition process. One can distinguish between **existing** and **original**¹⁴ sources of knowledge, or similarly between **public** and **private**¹⁵ knowledge. While public knowledge is stored in sources publicly available such as textbooks or articles, private knowledge is only available through a specific expert by personal contact. In this scheme literature can be classified as a typical example of public knowledge and human experts correspond to private knowledge.

Usually it is assumed that public knowledge sources do not contain sufficient knowledge for building a KBS. It is argued that it is best to use public knowledge for building a rough prototype such that the capabilities of the system are demonstrated. In the subsequent

¹¹ Reitman, Rueter (1987), pp. 152.

¹² Schmalhofer, Bergmann (1990), pp. 76.

¹³ Balachandra (1988), p. 109.

¹⁴ Chadha, Mazlack, Pick (1991).

¹⁵ Kerschberg, Dickinson (1988), pp. 129.

developing stages it is then recommended to add private knowledge containing heuristics and «rules of thumb» to improve the system.¹⁶

Although it may be true in principle that adding private knowledge to a knowledge base improves its performance, here it is argued that the value of public knowledge is far underestimated. It could contribute more valuable information to KBS's, if only it would be more appropriately used.

In existing systems only a small fraction of public knowledge is used in knowledge acquisition, if any at all. Much public knowledge rests unused for computational purposes, although it could be of considerable importance for the knowledge base.

Were it possible to develop methodologies that automate the process of knowledge elicitation and that find the relevant public knowledge or literature via appropriate criteria, the amount of public knowledge utilized could be increased by far.¹⁷ A much larger proportion of the knowledge could then be acquired through public sources. Knowledge acquisition, often described as the «bottleneck»¹⁸ or «major constraint»¹⁹ in the development of expert systems, could then be pursued rationally and more effectively. Hence, the quite modest results in this field of knowledge acquisition from literature may rather be traced back to a lack of well-founded methodologies regarding literature or public knowledge sources in general, than to a lack of knowledge available through these sources.

2.3. Literature as a source of knowledge

In this paper, the word «literature» is used to indicate publications in journals or textbooks that are relevant for a specific domain and publicly available. Company internal, textual documents like protocols are not included in this definition. KBS's that mainly use literature as their source of knowledge are called «textbook-expert systems».

2.3.1. Domain dependent relevance

Depending on the field of interest, literature has a different relevance in describing the domain specific knowledge; it can be a subsidiary or a dominant source of knowledge. The following examples will demonstrate this:

One typical application for knowledge based systems in engineering is fault diagnosis, e.g. of a specialized, complex machine in the manufacturing process. In this special domain

¹⁶ Kerschberg, Dickinson (1988), pp. 130 and Attarwala, Basden (1985), p. 145.

¹⁷ A lot of research is done in automating the knowledge acquisition process. This research concentrates on both, automating single stages of the process (e. g. finding relevant knowledge with Information Retrieval Systems) or automating the whole acquisition process with so called «parsers». In this paper this aspect of knowledge acquisition will not be discussed any further.

¹⁸ E.g.: Cullen, Bryman (1988), p. 216 and Arzine (1989). Wright, Ayton (1987), p. 14.

¹⁹ Reitman, Ruetter (1987), p. 152.

the relevant knowledge for detecting a fault is usually kept by a few human experts (possibly by only one). In many cases this knowledge is not documented at all. The literature in this field does not usually contain much relevant information, because of the uniqueness of the problem. To build a KBS in a domain like this, one must use the human expert as predominant knowledge source. Some documents may serve as subsidiary knowledge sources.

In the field of business, especially in the area of strategic management, the structure of information and the way knowledge is documented and communicated is different. Problems concerning this subject are discussed by professionals, working in businesses, as well as by scientists, working at universities or research institutes.

Scientists in particular tend to publish a lot of their knowledge and results of their research. Publications are one important measure of scientific output. Scientists are judged among other things by their publications; the phrase «publish or perish» circumscribes this condition quite well. The scientific community is international and communicates through books and journals. This literature is read by experts in the respective field. A steady discussion in a special field of research is taking place to a large extent through literature. Although experts in the respective fields are not available personally, their knowledge represented in textual form can be used for knowledge elicitation.

Hence, one can state that in the domain of business, literature is a very important source of knowledge that contains information often not available through other sources.

In general, one can assume an importance of literature for knowledge acquisition when the domain is of general interest and problems concerning this domain are discussed publicly via written media especially on the scientific level.

2.3.2. Characteristics of literature in strategic management

Literature in strategic management has several characteristics that are important in the process of knowledge acquisition:

- General availability of literature.
- Formulation in natural language.
- Usage of a professional terminology.
- Qualitative rather than quantitative information.
- Dominance of qualitative models.
- Multi-experts representing the domain knowledge.

A special methodology of knowledge acquisition is necessary to take into account the particular characteristics of the domain.

2.3.3. Former Studies

Knowledge acquisition using existing documents formulated in natural language on a broad basis is not very common. However, some attempts have been made using information like this in knowledge bases.

In the following some of the approaches are shortly reviewed concerning the knowledge acquisition aspect:

An expert system in marketing that selects media classes uses standardized business case studies for building the knowledge base.²⁰

In an advisory system for government regulations a methodology is given that transforms documents (regulations, specifications) into a knowledge base with a restricted form of English. This transformation is an important step towards formalization. This restricted form of English is both machine understandable and still understandable for humans.²¹

The knowledge based systems EXSTRABS²² and CASA²³ use textbooks in the process of knowledge acquisition. In the descriptions of these systems, the knowledge transformation from the textbook into a formalized language is described very briefly and is not comprehensible.

The system STRATASSIST also elicits knowledge from a textbook written by one expert and explicitly considers the fuzziness in linguistic terms. Nevertheless, this system only represents a small fraction of knowledge relevant in the domain. The knowledge base contains only 52 production rules, which is quite small. In this approach emphasis is placed on the fuzziness of natural language.²⁴

An interesting approach by Bünthe and Albers²⁵ uses meta-analysis to solve contradictory results of empirical studies. However, the process of knowledge acquisition is not described in detail, e. g. problems concerning uncertainty and imprecision of knowledge are not discussed. The formalization process of the knowledge therefore can not be evaluated in detail.

An adequate methodology of knowledge acquisition for the underlying project could not be found. The different approaches either use highly specialized documents in the knowledge acquisition process or do not seem to have a well-defined methodology. Knowledge acquisition often seems to be neglected altogether.

20 Chadha, Mazlack, Pick (1991).

21 Tazovitch, Matwin, Oppacher, Skuce, Szpakowicz (1986).

22 Lelke, Werners (1991).

23 Müller-Wünsch, Woltering (1990).

24 Green-Hall (1987), pp. 77.

25 Bünthe, Albers (1990).

3. Methodology for knowledge acquisition through literature

In this chapter a methodology for knowledge acquisition through literature is presented. The whole process is partitioned in several consecutive stages similar to a «life cycle»²⁶ that can be understood as a general framework.

The herein presented methodology can be classified accordingly to section 2.2. as direct, because it extracts the rules explicitly (directly) out of texts and model-based. The knowledge source is public or existing.

This process extends beyond to those presented in literature. While it is not in all cases applicable, however, it conforms to specific problems, transforming texts that are publicly available and formulated in natural language into formal knowledge base of a KBS.

Although this methodology is applied to a specific domain, it can be generalized for domains with similar characteristics.

Since it is rare for one person or author to have all the knowledge required²⁷, this methodology considers the knowledge of multiple experts in the knowledge acquisition process.

3.1. Search and evaluation of relevant literature

As soon as the domain of the KBS is defined, the first step in the knowledge acquisition process is identification of relevant literature. Criteria used to find appropriate human experts can serve to identify and evaluate relevant literature or authors.²⁸ Methods used in bibliometric analyses may also be helpful in this context.²⁹

Three different approaches finding the relevant literature are suggested.³⁰ To obtain best results, a combination of these methods is recommended.

Data bases:

One systematic way to find relevant literature is through computerized data bases. To obtain good results, literature data bases must be completely respective to the underlying field.

The data base must offer the user a variety of options, searching the literature relevant to a specific problem. The literature in these data bases is found through search-procedures that can contain keywords of the relevant problem or names of relevant authors.

²⁶ Nwana, Paton, et. al. (1991), p. 62.

²⁷ Boose, Gaines (1989), p. 382.

²⁸ An extensive review how to select domain experts is given in: Prerau (1990) pp. 173.

²⁹ Some bibliometric indicators are discussed in: Moed, Burger, Frankfort, Raan van (1985).

³⁰ Similar to: Hunter, Schmidt, Jackson (1982), pp. 146.

Citation analysis:

Additional literature can also be found through citations in texts of the relevant domain. The frequency with which papers and textbooks are cited in the literature can be regarded as a measure of influence within the scientific community. This influence or impact in turn can be interpreted as quality, although these two concepts do not necessarily coincide.³¹ An author, article or book that is cited very often seems to be of importance in the respective domain.

Expert judgements:

Another way to obtain relevant literature is through domain experts who recommend textbooks and articles containing important knowledge in the field of interest.³² One expert alone usually may not know all literature about a special problem; the judgement can also be influenced by personal interest. To improve this method it is suggested that numerous experts are asked to recommend literature by interviews or questionnaires. These results are likely to give a more complete list of literature.³³ The frequency of the recommendations of a certain text can serve as a measurement of importance in the respective domain.

Although it would be ideal to register all literature that could be of some importance in this stage, capacity problems in cost and time may force a restriction of the amount of literature to be considered. Since the texts have to be analyzed later on without automation, this is a time consuming process. Though the evaluation of the elicited knowledge is done in a later stage of the knowledge acquisition process, a screening of the literature may be necessary to get down to an amount of literature that can be handled.

The more the knowledge acquisition process can be rationalized through partial automation, the more literature can be considered in the process.

Citation analysis and the frequency of recommended texts can serve to locate the appropriate literature to be regarded in the early stages of knowledge acquisition.

Another way to restrict the amount of literature is through a ranking of the relevant journals; only journals that meet certain quality requirements in the respective field are considered in the knowledge acquisition process. Much knowledge in the scientific field is distributed through journals. Before an article is published, it is revised by the editors of the journals. Since an article is published in an acknowledged journal, one can presume a certain quality of the article.

This process yields a list of literature that is relevant for the specific domain; not just the knowledge of one, but that of many experts is represented in this list.

³¹ Righter (1986), p. 38.

³² Kerschberg, Dickinson (1988), pp. 130.

³³ Rigter (1986), p. 46.

3.2. Identification of relevant knowledge

The relevant knowledge for the domain has to be found in the texts selected before. This process leads to a significant reduction of the data.³⁴ In principle, one can distinguish between an automated and a manual way to find the relevant knowledge.

The relevant knowledge can be identified manually by the knowledge engineer who needs to have a certain degree of expertise in the domain or by an expert.³⁵

Considering the state-of-the-art, an automated identification of the knowledge seems partially feasible. It can at least be partly automated, if the relevant texts are available or transferrable in electronic form. Some progress to automate this process (Information Retrieval) has already been made and implemented in knowledge acquisition tools.³⁶

The knowledge has to meet two basic requirements to be of importance for the knowledge base:

- The single identified chunk of knowledge must be relevant to the concrete problem. Many statements in the texts are of general nature and do not describe relations relevant to the domain. These have to be omitted. Often only small parts of articles or books give information about the problem of interest.
- The relations must be transferable into an *if - then* rule. A conditional or causal relationship must be identifiable within the text. These relations can be described explicitly or implicitly. This may require a first interpretation in the knowledge acquisition process.

One can distinguish between two different classes of knowledge respecting their functions in the knowledge base, domain and process knowledge. **Domain knowledge** is represented as facts, rules and model components for a particular problem. **Process knowledge** refers to knowledge which is used to guide the development and use of a specific decision making model.³⁷ This knowledge is used to design and organize the inference engine.³⁸ For that purpose metarules are used in general.³⁹ Information about organization of the knowledge base in the text is quite rare. Structural information can often be extracted from graphs that demonstrate structures in a global way.

³⁴ Breuker, Wielinga (1987), S. 26.

³⁵ Schmidt, G., Schmalhofer (1990), p. 307 suggest a case-oriented knowledge acquisition methodology that uses texts to identify the appropriate domain-specific literature as well as the relevant text segments by an expert.

³⁶ E. g.: The System COKAM+ analyzes relevant knowledge from texts for an already existing model of expertise. The search of the relevant text segments is done through «keywords» and their synonyms. [Schmidt, G. (1991), pp. 7]

³⁷ McGovern, Samson, Wirth (1991), p. 264.

³⁸ Breuker, Wielinga (1987), p. 28.

³⁹ Metarules can be defined as "rules about rules". They can be located in between the knowledge base and the inference mechanism and control the reasoning process. [Farreny (1988), p. 52]

3.3. Documenting the domain knowledge

After identifying the relevant knowledge, it is transformed into a general format. This is in order to obtain a documentation that represents the knowledge to be considered in following stages of knowledge acquisition. It is suggested to use quasi-English/German *if-then* rules for this purpose.⁴⁰

Utilizing *if-then* rules for documenting the knowledge allows the knowledge to be acquired in independent chunks. These become the basis for a rule-based representation in the knowledge base.⁴¹ In literature it is stated that a rule-based KBS constitutes the best means available today for codifying the problem-solving know-how of experts. It seems that most expert knowledge can be expressed by a set of situation-action rules. This may be the reason that most of the existing KBS base on production rules.⁴²

The following format meets the requirement for building a transparent knowledge base. It documents the knowledge in a unique way. The following representation scheme is still independent respecting any special programming language or development shell.

In addition to the IF and THEN elements that contain the kernel of the information, other elements are included in the format to meet the requirements of knowledge acquisition defined above.

In the underlying project the knowledge is documented in the following format:

NO.:	Identification of the rule; the number of the rule in the knowledge document is related to the corresponding rule in the knowledge base.
SUBJECT:	This field serves to classify rules to rule-sets. Headlines of chapters or articles may give some hints concerning the classification.
IF:	Condition of the rule.
THEN:	Conclusion of the rule.
SOURCE:	Citation of the rule. Identification of the origin of the knowledge. This is a crucial aspect in maintaining the transparency and comprehensibility of the knowledge acquisition process.
COMMENT:	Two functions: <ul style="list-style-type: none"> - Explanations of the rules that are implemented in the knowledge base. - General comments that are necessary to understand the rule in context, e.g. cross-references to other rules, reliability of information, doubts.

Figure 1: Documentation format of relevant knowledge

⁴⁰ Prerau (1990), p. 213.

⁴¹ An overview of rule-based systems give Hayes-Roth (1987), pp. 963.

⁴² Nebendahl (1990), p. 57. An overview about advantages and disadvantages of rule-based systems can be found in: Jackson (1987), p. 240.

Basically the knowledge is documented the way it is found in the texts. A standardized terminology is not used in this stage yet. However, the texts do not always describe the knowledge in a way that makes it easy to transform it into a rule based (*if-then*) format. A cautious modification may be necessary to make it fit into the documentation format.

This document is generated incrementally; it is maintained continually during the entire course of knowledge acquisition. The following stages of the knowledge acquisition process can be started as soon as the document contains enough knowledge to represent a well-founded framework of the knowledge base.

The knowledge document becomes part of the final documentation of the project.

3.4. Reliability of knowledge

An important requirement of the knowledge implemented in a knowledge base is its reliability. A careless implementation of all information available does not lead to the quality level that is necessary to support complex decisions.

In the previous stages of knowledge acquisition the knowledge was elicited and documented; the reliability or quality of the knowledge has not been evaluated up to the current stage. Every statement that seemed to be relevant to the domain was included in the knowledge document. In order to obtain a knowledge base that is reliable, the documented knowledge has to be evaluated. Knowledge that does not meet the requirements of reliability must be excluded from the following stages of knowledge acquisition.

A concept is presented that gives a framework to estimate the reliability of the rules. The following classes of reliability are suggested:

<p>I. Facts Definitions</p>
<p>II. Scientifically proven knowledge</p> <ul style="list-style-type: none"> - Formally proven knowledge - Empirically proven knowledge
<p>III. Individual knowledge</p> <ul style="list-style-type: none"> - Experiences - «Rules of thumb» - Assumptions, conjectures - Heuristics
<p><i>Figure 2: Classes of reliability</i></p>

ad I. **Facts** contain information that can be obtained from information services, e.g. share value published in newspapers. This information is reliable and implemented in the knowledge base.

Definitions are necessary to clarify special terms. Definitions cannot be true or false.

ad II. Scientifically proven knowledge refers to rules based on studies usually distributed through literature. In business administration as in social sciences empirical findings are generally more frequent than formally deduced findings.

ad III. Individual knowledge is based on the expertise of a human expert. This knowledge is not scientifically proven, but it has developed from private experiences of the expert.

Heuristics are uncertain relations based on an assumption of typicality that are sometimes just a poorly understood correlation. These heuristics are often empirical, deriving from problem-solving experience, and they correspond to «rules of thumb».⁴³

In this context arises the question, which classes of reliability described above meet the requirements for implementation in a knowledge base. Guidelines or rules are required that help to classify and evaluate the rules.

Hauschildt⁴⁴ uses empirical sciences as a framework for evaluating knowledge and argues that only theoretically based, empirically well-founded findings should be utilized in the knowledge acquisition process.

In this methodology, theoretically based information is only to be taken into consideration when proven in reality. Empirically proven relationships that have not been theoretically based are also to be included in the knowledge base, if there are signs that they lead to an appropriate judgement.

What is excluded in this concept are theories that are empirically unconfirmed as well as individual experiences that cannot be evaluated objectively.

In contrast, other authors emphasize the value of individual knowledge and state that expert knowledge consists of «rules of thumb» and heuristics to some extent.⁴⁵ This point of view is contradictory to the requirements of knowledge described above.

In order to solve this problem, the following concept is suggested:

Facts are implemented when relevant for the knowledge base.

Definitions are implemented in order to clarify important terms.

43 Clancey (1985), pp. 295.

44 Hauschildt (1990).

45 E.g. Feigenbaum (1977).

Scientifically proven knowledge has to be judged more valuable concerning reliability than individual knowledge (e. g. assumptions) because it is systematically proven in reality. Therefore one can state the following:

Scientifically proven knowledge displaces individual knowledge.

The question which now arises is, whether to ignore individual experiences of experts, since there is no better (empirically proved) knowledge available, or to include it in the knowledge base, although it is not proven with scientific methods. Here it is stated that as far as the quality of the knowledge base can be improved, this individual knowledge should be considered.

Individual knowledge is implemented if indications for its reliability are given.

Criteria to judge the reliability of knowledge are:

- Reputation of author
- Redundancy of information (see 3.6.1.)
- Quality of knowledge source
- Expert judgement

These criteria may be helpful to evaluate reliability. However, an exact method to evaluate the reliability of individual knowledge cannot be suggested.

In the knowledge base the degree of reliability of the rule must be mentioned within the rule (e.g. in the explanatory field) so that the user of the KBS is aware of the fact that the rule deduced from the text may have a «reduced» reliability.

Rules with a lower reliability can be interpreted as inexact knowledge that has to be considered in the knowledge base with certainty factors.⁴⁶

However, it is quite difficult to classify the reliability of rules with regard to the scheme presented above. In underlying texts the information necessary to evaluate the reliability of rules often is not available. It can be quite difficult to decide whether a rule found in the text is derived by a well-founded methodology, or whether it is a statement without any foundation. Some relationships might be proven, although not shown in their respective texts. Others are derived by a poor empiric methodology what makes them also doubtful.

Although there are problems in evaluating the reliability of rules, the criteria presented above give a useful framework to classify degrees of reliability. This classification makes it easier to decide whether a rule meets the requirements to be considered in the ongoing knowledge acquisition process or not.

⁴⁶ Leung, Lam (1989), p. 208.

3.5. Formalization

In order to implement knowledge in a KBS expressed through natural language a formalization of the pre-structured, formatted knowledge is mandatory.

A general proceeding making this process rational and transparent is used.

The formalization stage has to consider many different aspects, e. g. words have to be transferred into variables, attributes have to be attached to variables, uncertainty and fuzziness have to be considered.

3.5.1. Synonyms

The first step in formalizing the knowledge is the reduction of vocabulary to a restricted, standardized terminology. Synonyms are reduced to one standard word. Synonyms are words (or phrases treated as words) that may be substituted one for the other.

An automation of this procedure is possible via a thesaurus that contains the vocabulary of the domain specific terminology.⁴⁷

Although it is desirable to rationalize this process, one has to be careful with an automated reduction of the documented rules. Slight semantic differences between words usually considered synonyms can change the meaning of the rule.

To avoid this effect, it is recommended that a data base system in which a thesaurus is implemented support a simplification of the vocabulary by suggesting the respective standardized word. Nevertheless, this suggestion should be confirmed by the knowledge engineer.

This process has two advantages; first, the process is more rational than doing it manually, and second it is homogeneous because of the use of a standardized thesaurus, and subjective assignment is therefore suppressed.

3.5.2. Logic terms

Besides reducing vocabulary it is necessary to translate words or phrases expressing logical relationships into formal, logic expressions, e. g. «greater than» is transformed into « > » and «is» is transformed into « = ».

One problem arising in the formalization process is the transformation of the conjunctives «and» and «or» into a formal, mathematical language. The meaning of these words in natural language is quite different than their meaning in formal language. Special peculiarities have to be considered when transforming these words into formal language in order not to alter the meaning of the original knowledge.

⁴⁷ A similar proceeding is suggested in the «computer-aided content analysis» presented by Schmidt, R. (1981), pp. 361.

One can distinguish between an inclusive and an exclusive «or». The exclusive meaning of «or» represents a statement that could also be expressed with the term "either ... or", meaning that only one thing or the other is allowed.

The inclusive meaning of «or» represents statements expressing that both of the partial statements can happen at the same time. In formal logic and computer logic the inclusive «or» is more common.⁴⁸

In the process of formalizing natural language, one has to be aware of the possible ambiguities.

The meaning of «and» in natural language is not as restrictive as in logic. The knowledge engineer has to decide how to translate this word depending on the context.

This problem is strongly related to the aggregation of data connected with the conjunctions «and» and «or» in natural language (see section 3.7.).

3.5.3. Imprecision and uncertainty in reasoning

The expert knowledge that must be represented in the knowledge base is often expressed with imprecision and uncertainty.

Imprecision has to do with the content of a piece of information. Words used to express a piece of knowledge do not necessarily have a unique and precise interpretation, but cover a set of values of parameters whose limits are often known only approximately. Different experts might also assign different values to the words.

Uncertainty refers to the truth or falsity of propositions representing factual or operational pieces of knowledge.⁴⁹

Although imprecision and uncertainty are different respecting their origins, they are dependent in some respects. If an expert has to be precise, he will weigh his judgements with confidence coefficients. If he is allowed a certain degree of fuzziness, i. e. using words not numbers in describing relationships, he may sometimes be able to avoid the use of uncertainty coefficients.⁵⁰

3.5.3.1. Uncertainty in causal relationship

Uncertainty in knowledge based systems can be modeled by two different approaches, the «Bayesian» approach and the «certainty factor» approach. In the certainty factor approach numbers, called certainty factors, are assigned to a proposition as a measure of belief in the truth of a conclusion. The Bayes' approach quantifies uncertainty in a

⁴⁸ Hart (1986), pp. 92.

⁴⁹ Dubois, Prade (1988), p. 67.

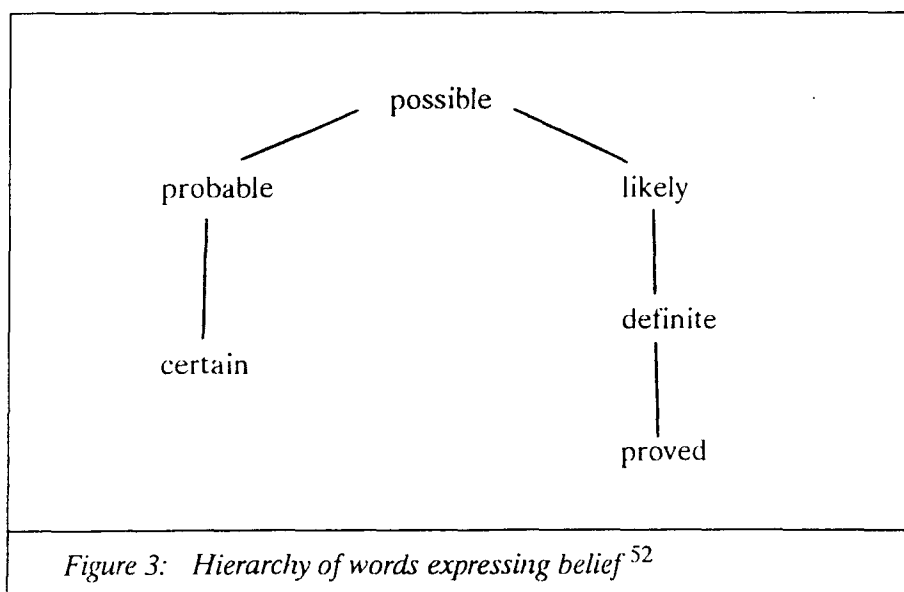
⁵⁰ Dubois, Prade (1988), p. 67.

probabilistic manner and assumes that two or more pieces of evidence in any rule are independent which is not true in general.⁵¹

This uncertainty in verbal or textual communication is mostly described in linguistic terms, statements including explicitly (subjective) numerical probabilities being quite rare. The task arising here is to transform these certainty-expressing linguistic terms into numerical certainty factors. Since these terms are imprecise too, the problems of imprecision and uncertainty are to be solved within one word mutually.

The process of transforming these linguistic terms into certainty factors can be subdivided into two steps. First, the linguistic terms are brought into a hierarchical order, so that one has a kind of ranking, and second, certainty factors are assigned to these words.

Hart suggests a hierarchy that represents relationships between words expressing belief; a similar structure is present in the German language.



These probability expressions can be associated with numerical probabilities. Empirical tests were done to confirm these numerical values. The mean of the numerical values can be used for implementation. The range of the associated numerical values is quite high, which demonstrates the fuzziness in these linguistic terms.⁵³ Another classification of words expressing belief is implemented in the system MYCIN.⁵⁴ Both, uncertainty and fuzziness can be supported by expert system shells.⁵⁵

⁵¹ Magill, Leech (1991)

⁵² Hart (1986), p. 100.

⁵³ Wright, Ayton (1987), p. 23.

⁵⁴ Harmon, King (1987), p. 48.

⁵⁵ E. g.: Leung, Lam (1989).

3.5.3.2. Imprecision in linguistic terms

Because words are less precise than numbers, they are appropriate to characterize approximate phenomena which are too complex or too ill-defined to be amendable to description in conventional quantitative terms. Since these inexact expressions cannot be used by precise algorithms, another class of models, «fuzzy logic», is suggested that supports this type of approximate reasoning.⁵⁶

One can distinguish between qualitative and quantitative attributes. Qualitative attributes do not have a quantitative base that makes a verbal expression necessary. For quantitative attributes it is assumed that numerical information basically is given; in principle they are measurable on a numerical base. However, also in this case a verbal description for situations is often preferred; a multitude of verbal expressions are quantitative in origin these can be traced back to a numerical base. In this cases an abstraction or classification of the quantitative base is made; it is done subjectively and depends on the context.⁵⁷

3.6. Redundancy and conflicting knowledge

A KBS that derives from one individual's lines of reasoning or understanding will most likely be limited in some respect. Systems that contain knowledge of a group of authors (experts) are likely to function more effectively and may prove more useful.⁵⁸ Additionally, if no single author describes a problem completely, the knowledge acquisition from multiple authors is a necessity.

As soon as the knowledge of several experts or authors is considered within one knowledge base, additional problems arise that have to be solved. It is likely that several authors make statements about a certain relationship. These statements may be identical, which leads to the problem of redundant information. They may also contain conflicting information, leading to the problem deriving a meaningful solution out of this conflicting basis.

Depending on the way that multi-expert knowledge is integrated in the knowledge acquisition process one can distinguish between **nonconflicting** and **conflicting** multi-expert knowledge bases. In the first category each expert only contributes the knowledge in a particular area of expertise; he is responsible only for a special subdomain, for which he contributes the knowledge exclusively. The second category refers to knowledge bases that represent the knowledge of two or more experts in the same field of expertise. Under this circumstance problems with redundant and conflicting knowledge appear that have to be solved.⁵⁹

⁵⁶ The use of fuzzy logic in knowledge-based systems is discussed e. g. in: Zadeh (1983).

⁵⁷ Werners (1990), pp. 3.

⁵⁸ Mittal, Dym (1985), p. 33.

⁵⁹ Reboh (1989), p. 145.

3.6.1. Redundant knowledge

Many experts express their results in different ways within the same text. This form of redundancy appears in conflicting as well as in non-conflicting knowledge bases. It can be removed by erasing redundant rules or, leading to the same result, by combining several redundant rules into one.

Another type of redundancy arises between two or more experts; whole rules or parts of rules can describe the same relations. The redundancy can be removed as above by combining the redundant rules into one. Whereas in the former case the redundancy does not have any influence on the rule itself, in the latter case it contains information concerning the reliability of the rule. If many acknowledged authors share the same opinion or find the same relationships, this can be interpreted as an increase of reliability or a confirmation of the rule. This type of redundancy yields additional information, serving to confirm the quality of the knowledge base.

3.6.2. Conflicting knowledge

While the types of redundancy described above are not critical, more problems arise when different authors contradict or disagree concerning a particular piece of knowledge. Adequate solutions have to be found to solve this problem.

Although it is recommended to divide the domain into subdomains, one usually still has more than one expert or author in the respective subdomain. The problem of conflicting knowledge still remains to be solved.

Several ways to cope with conflicting knowledge already have been discussed in literature. Alexander and Evans⁶⁰ suggest three approaches that try to solve problems arising within the knowledge representation of multiple experts:

Consensus methods:

This approach is subdivided into **analytical** and **interactive** methods. In an analytical method for example, the experts are assigned weights, the consensus then being obtained by calculating a weighted average of the outcome of the rule. Information from each expert is considered in the solution.⁶¹

Reboh suggests that a consensus can be achieved by assigning weights to the various sources of expertise to reflect the belief (confidence) in the respective competence of each source, and then combine the rules from each source according to those weights.⁶²

Criteria to derive the weights are not mentioned.

⁶⁰ Alexander, Evans (1988), pp. 47.

⁶¹ Morris (1977), pp. 686.

⁶² Reboh (1989), p. 146.

An extreme type of the consensus method is to use one author as primary expert⁶³ or a «knowledge czar».⁶⁴ To identify a dominant expert, this process requires a kind of ranking of the authors that represents their quality of expertise or reputation in the domain of interest. The knowledge of the primary expert displaces the knowledge of other experts.

It is also recommended to have one expert act as an overall system expert, responsible for integrating all the subdomain knowledge into a single system.⁶⁵

In interactive methods, each expert is provided information on the judgment of the individuals within the group and is provided an opportunity to revise his judgement. This method corresponds to the Delphi-approach.

Consensus about differing points of view can also be obtained by arriving at a single «best» solution by discussion.⁶⁶ These interactive approaches cannot be applied with literature as the knowledge source, since there is no opportunity to interact with the authors of the writings.

Selection of a specific line of reasoning:

This approach does not try to derive a consensus, but to select one solution. First the system needs information about the decision situation. Based on this, one line of reasoning is selected. Multiple lines of reasoning are allowed to exist without unwanted interactions which could compromise an expert's advise. The assumption for this approach is that each expert's line of reasoning is based on his unique experiences in the problem domain and therefore represent a distinct philosophy regarding the problem domain.

Blackboard systems:

These systems increase the independence among knowledge sources by appropriately dividing the problem domain. The expertise is divided among subdomains within a domain and the experts cooperate to solve the problem. The interaction, however, is kept to a minimum. The medium of interaction is referred to as the «blackboard», which records intermediate results. On this blackboard the different results of the experts are listed. Depending on conditions that are implemented, it is decided which result is used for the ongoing reasoning process.

Since the methodology presented herein uses multi-authors to build the knowledge base, it has to cope with conflicting statements in literature.

⁶³ Prerau (1985).

⁶⁴ Chadha, Mazlack, Pick (1991), p. 7.

⁶⁵ Prerau (1990), p. 194 and Harmon, King (1987), p. 223.

⁶⁶ Wolf (1989), p. 139.

The following methodology is suggested to cope with conflicting knowledge:

Rules based on different models are implemented separately so that there are different lines of reasoning. If there are conflicting rules within one model a variation of the consensus method is suggested; before implementing the conflicting knowledge a sort of consensus must be generated. This is done by ranking the rules based on certain criteria, first of all on the reliability. However, it is also possible to include several conflicting rules in the knowledge base simultaneously, to indicate to the user that in this particular field there are contradictory findings or opinions.

The following criteria can be used to evaluate conflicting rules:

- Reliability of the rule: (see: 3.5.) Although it is difficult to operationalize reliability, this is the most important criterion to evaluate knowledge; it displaces the other criteria. According to this criterion, rules that are derived by empirical studies are preferred to rules based on individual knowledge.
- Reputation of the author or journal: Criteria to identify the right expert can be applied to evaluate the reputation of the author. Citation analysis is also a possible approach.⁶⁷
- Date of publishing: New publications may take into consideration the newest developments and facts available to deduce an updated relationship that can be transformed into a rule. This is a subordinate criterion to evaluate rules.

3.7. Aggregation of knowledge

In order to derive results from the knowledge base, the single attributes of variables have to be combined in the process of reasoning.

This process is a multi-criteria decision making process; judgements have to be made in the presence of multiple criteria.⁶⁸ These criteria have to be aggregated with an appropriate methodology that considers the human aggregation behavior and derives results similar to human experts.⁶⁹

In natural language the connection between variables is usually described with the conjunctions «and» and «or». These conjunctions are used in natural language differently than their meanings in formal language. Whereas «and» represents the minimum and «or» the maximum of a set of values in formal language, human experts seem to use compensatory procedures when aggregating data.⁷⁰

Since these conjunctions have different meanings in natural than in formal language, special approaches have to be applied to aggregate the values of variables in the

⁶⁷ E. g.: Prerau (1990), pp. 173.

⁶⁸ Ko, Lin (1988), p. 34 and Chandrasekaran, Ramesh (1987).

⁶⁹ Different models are suggested and tested by: Zimmermann, Zysno (1983).

⁷⁰ Zimmermann, Zysno (1980).

underlying text.

Depending on the situational meaning of these words, alternative computational methods have to be applied in the aggregation process in order to represent the meaning of the underlying text. The knowledge engineer must select one method that is appropriate for the problem.

One approach that does not in principle distinguish between «and» and «or» is presented by Werners.⁷¹ Tests on empirical data have shown a close approximation between the human aggregation behavior in decision making and the model.

The aggregation process can be described as «fuzzy and» or «fuzzy or». The clear cut distinction between «and» and «or» disappears in this model; «and» is represented as an weighted additive combination of the minimum and the mean of the values, «or» is represented as a combination of the maximum and the mean. However, in this model one can also represent the logical meaning of «and» and «or» in extreme cases. In this case «and» is represented by the minimum, «or» by the maximum of the respective values.

In a study testing many different models of aggregation for «and», it was found that in the presence of many decision criteria and a complex problem (credit evaluation), the experts aggregated the single results by calculating the arithmetic mean.⁷²

4. Summary

In this paper a methodology designed for knowledge acquisition through literature is presented. It mainly fits strategic business problems, but is also applicable in domains with similar characteristics. In contrast to other methodologies that use documents in textual forms, this approach tries to incorporate public knowledge to a large extent. In several subsequent steps this knowledge is elicited, documented, evaluated and formalized.

The result of this methodology is a formalized and structured knowledge document that is well-prepared for implementation in a rule-based KBS.

Emphasis is laid on problems concerning the evaluation and interpretation of the content rather than on technical problems arising in this context. Implementation, testing and verification of the knowledge base are subsequent stages to occur after knowledge acquisition and are not described within this paper.

⁷¹ Werners (1990), pp. 11.

⁷² Rommelfanger, Unterharnscheidt (1988).

REFERENCES

- Alexander, S. M., Evans, G. W. (1988): The Integration of Multiple Experts: A Review of Methodologies, pp. 47-53. In: Turban, E. and P. R. Watkins (Eds): Applied Expert Systems. Amsterdam, New York, Oxford, Tokyo: Elsevier North Holland.
- Ansoff, H. I. (1976): Managing Surprise and Discontinuity - Strategic Response to Weak Signals. *Zeitschrift für betriebswirtschaftliche Forschung*, Vol. 28, pp. 129-152.
- Attarwala, F. T., Basden, A. (1985): A methodology for constructing expert systems. *R&D Management*, Vol. 15, pp. 141-149.
- Arzine, B. (1989): A Natural Language Front-End for Knowledge Acquisition. *SIGART Newsletter*, No. 108, Knowledge Acquisition Special Issue, pp. 106-114.
- Balachandra, R. (1988): An Expert System for R&D Projects. In: Turban, E. and P. R. Watkins (Eds): Applied Expert Systems. Amsterdam, New York, Oxford, Tokyo: North Holland.
- Boose, J. H., Gaines, B. R. (1989): Knowledge Acquisition for Knowledge-Based Systems: Notes on the State-of-the-Art. *Machine Learning*, Vol. 4, pp. 377-394.
- Breuker, J., Wielinga, B. (1989): Models of expertise in knowledge acquisition. In: Guida, Tasso (Eds): Topics in Expert System Design: Methodologies and Tools. Amsterdam: North-Holland.
- Breuker, J., Wielinga, B. (1987): Use of Models in the Interpretation of Verbal Data, pp. 17-44. In: Kidd, A. L. (Ed): Knowledge Acquisition for Expert Systems. New York: Plenum Press.
- Bünthe, S., Albers, S. (1990): Einsatzmöglichkeiten von Textbook-Expertensystemen in mittelständischen Unternehmen. *Betriebswirtschaftliche Forschung und Praxis*, Vol. 43, pp. 561-577.
- Chadha, S. R., Mazlack, L. J., Pick, R. A. (1991): Using Existing Knowledge Sources (cases) to Build an Expert System. *Expert Systems*, Vol. 8, No. 1, pp. 3-12.
- Chandrasekaran, G., Ramesh, R. (1985): Microcomputer Based Multiple Criteria Decision Support System for Strategic Planning. *Information & Management*, Vol. 12, p. 163-172.
- Clancey, W. J. (1985): Heuristic Classification. *Artificial Intelligence*, Vol. 27, pp. 289-350.
- Cullen, J., Bryman, A. (1988): The Knowledge Acquisition Bottleneck: Time for Reassessment. *Expert Systems*, Vol. 5, No. 3, pp. 216-225.
- Dubois, D., Prade, H. (1988): Processing of Imprecision and Uncertainty in Expert System Reasoning Models, pp. 67-88. In: Ernst, C. J. (Ed): Management Expert Systems. Wokingham, Reading, Menlo, New York, Don Mills, Amsterdam, et al.: Addison-Wesley.

- Farreny, H. (1988): Expert Systems and Knowledge Representation Languages, pp. 45-65. In: Ernst, C. J. (Ed): Management Expert Systems. Wokingham, Reading, Menlo, New York, Don Mills, Amsterdam et, al.: Addison-Wesley.
- Feigenbaum, E. A. (1977): The Art of Artificial Intelligence: I. Themes and case studies of knowledge engineering. In: *Proceedings Fifth International Joint Conference on Artificial Intelligence*, August 1977, Cambridge, MA, pp. 1014-1029.
- Green-Hall, N. (1987): A Fuzzy Decision Support System for Strategic Planning, pp. 77-90. In: Sanchez, E. and L. A. Zadeh (Eds): Approximate Reasoning in intelligent Systems, Decision and Control. Oxford, New York, Beijing, Frankfurt, Sao Paulo, Sydney, Tokyo, Toronto: Pergamon Press.
- Harmon, P., King, D. (1987): Expertensysteme in der Praxis. 2. Aufl., München Wien: Oldenbourg.
- Hart, A. (1986): Knowledge Acquisition for Expert Systems. New York St. Louis San Francisco Montreal Toronto: McGraw-Hill.
- Hauschildt, J. (1990): Methodische Anforderungen an die Ermittlung der Wissensbasis von Expertensystemen. *Die Betriebswirtschaft*, Vol. 50, No. 4, pp. 525-537.
- Hayes-Roth, F. (1987): Rule-Based Systems. In: Shapiro, S. C. (Ed): Encyclopedia of Artificial Intelligence. Wiley-Interscience Publication.
- Hunter, J. E., Schmidt, F. L., Jackson, G. B. (1982): Meta-Analysis - Cumulating Research Findings Across Studies. Beverly Hills, London, New Delhi: Sage Publications.
- Jackson, P. (1987): Expertensysteme - Eine Einführung. Bonn, Reading, Menlo Park, New York et al.: Addison-Wesley Publishing Company.
- Kerschberg, L, Dickinson, J. (1988): FINEX: A PC-based Expert Support System for Financial Analysis, pp. 111-133. In: Ernst, C. J. (Ed): Management Expert Systems. Wokingham, Reading, Menlo, New York, Don Mills, Amsterdam, et al.: Addison-Wesley.
- Ko, C.-E., Lin, T. W. (1988): Multi Criteria Decision Making and Expert Systems, pp. 33-45. In: Turban, E. and P. R. Watkins (Eds): Applied Expert Systems. Amsterdam, New York, Oxford, Tokyo: North Holland.
- Lelke, B., Werners, B. (1991): Modellierung und Implementierung von EXTRABS: Ein Expertensystem zur Branchenstrukturanalyse der strategischen Planung. Arbeitsbericht 91/1, Institut für Wirtschaftswissenschaften, RWTH Aachen.
- Leung, K. S., Lam, W. (1989): A Fuzzy System Shell Using Both Exact and Inexact Reasoning. *Journal of Automated Reasoning*, Vol. 5, pp. 207-233.
- Luconi, F. L., Malone, T. W., Morton, M. S. S. (1986): Expert Systems: The Next Challenge for Managers. *Sloan Management Review*, pp. 3-14.
- Magill, W. G. W., Leech, S. A. (1991): Uncertainty Techniques in Expert System Software. *Decision Support Systems*, Vol. 7, pp. 55-65.

- Marchant, H. (1990): Aus der Praxis der Wissensakquisition. *Künstliche Intelligenz*, Vol. 4, No. 2, pp. 61-63.
- McGovern, J., Samson, D., Wirth, A. (1991): Knowledge Acquisition for Intelligent Decision Systems. *Decision Support Systems*, Vol. 7, pp. 263-272.
- Mintzberg, H., Raisinghani, D., Theoret, A. (1976): The Structure of "Unstructured" Decision Processes. *Administrative Science Quarterly*, Vol. 21, S. 246-275.
- Mittal, S., Dym, C. L. (1985): Knowledge Acquisition from Multiple Experts. *AI Magazine*, Vol. 6, pp. 32-36.
- Mockler, R. J., Dologite, D. G. (1988): Developing Knowledge-based Systems for Strategic Corporate Planning. *Long Range Planning*, Vol. 21, No. 1, pp. 97-102.
- Moed, H. F., Burger, W. J. M., Frankfort, J. G., Raan van, A. F. J. (1985): The Use of Bibliometric Data for the Measurement of University Research Performance. *Research Policy*, Vol. 14, S. 131-149.
- Morris, P. A. (1977): Combining Expert Judgements: A Bayesian Approach. *Management Science*, Vol. 23, No. 7. pp. 679-693.
- Müller-Wünsch. M., Woltering, A. (1990): Computergestützte Strategieberatung für den Mittelstand. pp. 523-544. In: Ehrenberg, D., Krallmann, H., Rieger, B. (Eds): Wissensbasierte Systeme in der Betriebswirtschaft. Grundlagen Entwicklungen Anwendungen. Berlin, Heidelberg, New York: Springer.
- Nebendahl, D. (Ed) (1990): Expertensysteme. Teil 1 - Einführung in Technik und Anwendung. Berlin, München: Siemens Aktiengesellschaft.
- Nwana, H. S., Paton, R. C., Bench-Capon, T. J. M., Shave, M. J. R. (1991): Facilitating the Development of Knowledge Based Systems. *Artificial Intelligence Communication*, Vol. 4, No. 2/3, pp. 60-73.
- Orsini, J.-F. (1986): Artificial Intelligence: A Way Through the Strategic Planning Crisis? *Long Range Planning*, Vol. 19, No. 4, pp. 71-77.
- Prerau, D. S. (1990): Developing and Managing Expert Systems: Proven Techniques for Business and Industry. Reading, Menlo Park, New York, Don Mills, Wokingham, Amsterdam, Bonn et al.: Addison-Wesley.
- Prerau, D. S. (1985): Selection of an Appropriate Domain for an Expert System. *AI Magazine*, Vol. 6, pp. 26-30.
- Rajan, T., Motta, E., Eisenstadt, M. (1988): ACQUIST: A Tool for Knowledge Acquisition, pp. 113-125. In: Kelly, B. (Ed): Research and Development in Expert Systems V. New York, New Rochelle, Melbourne, Sidney: Cambridge University Press.
- Reboh, R. (1989): Extracting Useful Advice from Conflicting Expertise. *ACM SIGART Newsletter*, No. 108, pp. 145-150.

- Reitman J. S., Rueter, H. H.(1987): Extracting Expertise from Experts: Methods for Knowledge Acquisition. *Expert Systems*, Vol. 4, No. 3, pp. 152-168.
- Rigter, H. (1986): Evaluation of Performance of Health Research in the Netherlands. *Research Policy*, Vol. 15, pp. 33-48.
- Rommelfanger, H, Unterharnscheidt, D. (1988): Modelle zur Aggregation von Bonitätskriterien. *Zeitschrift für betriebswirtschaftliche Forschung*, Vol. 40, No. 6, pp. 471-487.
- Rowe, A. J., Somers, I. A., Schutt, H. (1988): Management Use of Artificial Intelligence, pp. 55-69. In: Turban, E. and P. R. Watkins (Eds): *Applied Expert Systems*. Amsterdam New York Oxford Tokyo: North Holland.
- Schmalhofer, F., Bergmann, R. (1990): Case-Based Knowledge Acquisition: Extending Expert Problem Solutions for Technical Planning Tasks, pp. 76-89. In: Thakar, S. (Ed): *Tagungsband 2. Workshop Knowledge Engineering zum Thema Modellbegriff des Knowledge Engineering*. Berlin.
- Schmidt, G. (1991): COKAM+: Fall-orientierte und Modell-orientierte Wissensakquisition aus Texten. ARC-TEC Diskussionspapier. Deutsches Forschungszentrum für Künstliche Intelligenz. Kaiserslautern.
- Schmidt, G., Schmalhofer, F. (1990): Case-Oriented Knowledge Acquisition from Texts, pp. 302-312. In: Wielinga, B., Boose, J., Gaines, B., Schreiber, G., Someren, M. (Eds): *Current Trends in Knowledge Acquisition*. Amsterdam, Washington DC, Tokyo: IOS Press.
- Schmidt, R. (1981): Diagnose von Unternehmensentwicklungen auf Basis computergestützter Inhaltsanalyse, pp. 353-379. In: Bratschitsch, R. (ed.): *Unternehmenskrisen - Ursachen, Frühwarnung, Bewältigung*. Stuttgart: Poeschel.
- Swaby, P. A. (1990): Towards Large Knowledge Bases: Automating Knowledge Elicitation, Knowledge Verification and Knowledge Base Building, pp. 215-225. In: Addis, T. R., Muir, R. M. (Eds): *Research and Development in Expert Systems VII*. Cambridge, New York, Port Chester, Melbourne, Sidney: Cambridge University Press.
- Tauzovich, B., Matwin, S., Oppacher, F., Skuce, D., Szpakowicz, S. (1986): An Expert Advisory System for Government Regulations: Knowledge Acquisition Methodology, pp. 205-212. In: Pau, L. F. (Ed): *Artificial Intelligence in Economics and Management*. Amsterdam New York Oxford Tokyo: North Holland.
- Werners, B. (1990): Modellierung und Aggregation linguistischer Terme. Arbeitsbericht 90/03, Institut für Wirtschaftswissenschaften RWTH Aachen.
- Wolf, W. A. (1989): Knowledge Acquisition from Multiple Experts. *SIGART Newsletter*, No. 108, pp. 138-140.

- Woodward, B. (1990): Knowledge acquisition at the front end: defining the domain. *Knowledge acquisition*, Vol. 2, pp. 73-94.
- Wright, G., Ayton, P. (1987): Eliciting and Modelling Expert Knowledge. *Decision Support Systems*, Vol. 3, pp. 13-26.
- Zadeh, L. A. (1983): The Role of Fuzzy Logic in the Management of Uncertainty in Expert Systems. *Fuzzy Sets and Systems*, Vol. 11, pp. 199-227.
- Zimmermann, H.-J., Zysno, P. (1983): Decisions and Evaluations by Hierarchical Aggregation of Information. *Fuzzy Sets and Systems*, Vol. 10, pp. 243-260.
- Zimmermann, H.-J., Zysno, P. (1980): Latent Connectives in Human Decision Making. *Fuzzy Sets and Systems*, Vol. 7, pp. 37-51.