Discovering Tacit Knowledge in Business Decision Making

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Abstract: - In dynamic and globalized business environment the only certain source of lasting competitive advantage of companies is knowledge. By maintaining and acquiring relevant knowledge through the use of knowledge management systems businesses are sustaining their competitive advantage over other players in the market. In this sense one of the most important activities is decision making. Decision making process must take into account all of the relevant knowledge in order to reach optimal decision, specifically knowledge that is not available to other competitors – tacit knowledge. In this paper we propose an information-driven approach that can be used to make model of knowledge that management executives and experts posses. The model can reveal new relations that have not been explicitly articulated during the knowledge engineering process. In the case study that will be described in this paper, knowledge was used to determine the criteria for evaluation of various decision options during a selection of IT Security solution for the organisation. The information-driven approach is based on the modified ID3 algorithm implemented in the DoctuS expert system shell. Results of the developed knowledge model is presented and discussed.

Key-Words: - Tacit knowledge, Knowledge Management, Knowledge discovery, Decision-making, Decision support systems, IT management

1 Introduction

In order to take maximize advantages of the currently available technologies it is essential to empower employers and managers with the skills required to rationalize their exploitation of implemented ICT systems. Employees acquire knowledge through different types of education, either formal or informal throughout their lives. This knowledge eventually becomes a comparative advantage of the organization itself. Creation and utilization of knowledge is becoming the primary activity in the creation of national wealth.

Due to the high importance of knowledge as an asset representing comparative advantage of the organisation its maintenance requires well structured knowledge management systems [5] that can both acquire new knowledge emerging in the organisation and employ the obtained knowledge efficiently. These systems can store and use well structured explicit knowledge. But the true competitive advantages are contained in a type of knowledge that cannot be explicitly defined – tacit knowledge. In order to incorporate at least some of the tacit knowledge form the knowledge owners (i.e. employees and managers) a knowledge engineering effort must be undertaken.

In this paper we present the information-driven approach to knowledge engineering that can unveil relations between different segments of knowledge that the knowledge owners cannot explicitly express. The information-driven approach can provide knowledge owners and decision makers with the integral overview of the knowledge domain consisting of the information provided by all of the team members. During this process contradictions in knowledge base can be discovered and corrected thus enhancing the understanding of the problem domain of all the members involved. One of the most important strengths of this approach is that it eliminates the need to convert qualitative sets of properties into quantitative measures of performance. In this way no additional and false information is incorporated in the knowledge base. The decision making process based on the resulting knowledge base enables better modelling and evaluation of the problem at hand and reaching a better decision.

The structure of this paper is as follows: In Section 2 business decision types and their relation to explicit and tacit knowledge are introduced. In Section 3 we will present the modified ID3 algorithm for inductive decision trees that is the basis of the information-driven approach to knowledge engineering. This algorithm is implemented using DoctuS Expert System Shell which will also be described. In the following section a case study is presented. Knowledge base that contains expertise about evaluating IT Security solutions developed using DoctuS Expert System Shell is described. In Section 5 results will be presented, followed by a conclusion and final remarks.

2 Tacit Knowledge and Business Decisions

Knowledge is the most important asset of today's companies. It can take a number of different forms that can be classified in a number of ways [3] [15] [17]. All of these classifications acknowledge that the knowledge is subjective. Knowledge is dependable on individual's cognition and interpretation (subjective constituent) of the relations of the real world (objective constituent). If we consider the degree of subjectivity and objectiveness in knowledge we can distinguish between three types of knowledge. These are facts (with emphasis on objectiveness), skills (with even emphasis on subjective and objective constituent) and intuition (with prevailing subjectivity constituent).

For each of these types there are two possible levels of awareness of the knowledge holder – the focal and subsidiary awareness [15]. In this way facts can be facts about events and ponderable facts; skills can be activity skills and competence skills; intuition can be explanatory intuition and premonitions. All types of knowledge make up the organisational knowledge and therefore it is a challenging task to transfer all of required knowledge between employees and managers in order to include it into business processes of the organisation (see for example [10]).

One of the tasks most dependable on knowledge is the decision making process. According to Haddad [7], there are 5 important characteristics of decision making process that are crucial for reaching correct economic decisions: 1. structure or level of decision-making, 2. procedure of decision making, 3. the information flows, 4. decision-making criteria and 5. incentives for formulating and executing decisions [7].

We have already explained that the information flows demand appropriate level of knowledge management system in order to reach local knowledge that can be relevant for the decision process. In the remainder of this paper we will present an approach to determine the criteria for evaluation of decision options and reaching of the optimal decision. First we will mention types of decisions that can be delivered through the decision making process.

The simplest type of decision is *reflexive decision*. It is a decision made by instinct and therefore requires no prior experience or extraction of any tacit knowledge.

If the decision can be made using prior experience of similar problems then it is a *routine decision*. This type of decision requires sound organisation of prior experience, usually in terms of business rules or rules of conduct. The final decision is made by acting according to the applicable rules form the known rule set. The rule set can be updated as the additional experience in decision making is acquired. The rule set contains explicit knowledge about the problem domain so tacit knowledge is not require for the decision making process.

The most complex type of decision is the *original decision*. This type of decision cannot be made on instinct due to significant consequences for stakeholders and because there are no mechanism (legal or other) that can eliminate the requirement of performing the evaluation of decision options based on knowledge. In this case there is no prior experience or rule set (i.e. explicit knowledge) about the problem domain so implicit knowledge i.e. tacit knowledge must be used. Tacit knowledge has no clearly defined attributes or values so the quality of the decision depends highly on the skills and experience of the decision maker (for example see project manager guidelines in Tarawneh et al [18]).

In order to support the decision making process the evaluation of different decision options is crucial [9]. Existing forms of evaluation of decision solutions, especially *ex ante* methods of predictive and forecasting models, are not entirely appropriate. Hochstrasser and Griffiths [8] argue than many evaluation techniques are inadequate, particularly those which are based purely

on numeric measures. Most of the relevant features of decision options are qualitative and thus hardly comparable. This is why information driven approach such as decision tree learning and ID3 algorithm seem more appropriate.

3 ID3 algorithm and DoctuS

Information-driven approach to decision support systems is based on the qualitative features of the decision criteria instead on interpolation of quantitative values that may not adequately describe properties of suggested solutions.

Decision tree learning is an example of this kind of approach. Some of the most successful applications of decision tree learning use ID3 algorithm. ID3 algorithm [16] is an attribute-based induction learning system. It is an iterative algorithm used to construct decision trees based on a training set of example cases. For each node in the decision tree attribute with the highest information gain is chosen to split the tree. The algorithm prefers simpler decision trees by eliminating attributes without positive information gain in accordance with the principle known as the Occam's razor. The original ID3 algorithm is a heuristic, though, because of unordered set of attributes used for decision tree construction. The derived decision tree represents a model of knowledge contained in starting examples and therefore can be used to construct production rules.

In the case of decision making, each attribute A of a possible solution $S(j)$ can have a number of values v.

$$S(j) = \{A_i(j): \{v_1(i), v_2(i), \ldots v_m(i)\}, i=1,2,\ldots n\}$$

These values v have different level of desirability function $D(x)$ so that they form an ordered list:

$$A_i=\{[v_1, v_2, \ldots v_n], \quad \forall v_n: D(v_{n-1}) < D(v_n)\}.$$

If these values are known for a set of proposed solutions we can calculate information gain for each attribute used, using information entropy for each attribute

$$E(A_i) = - \Sigma f(v_n(i)) \log[f(v_n(i))]$$

Information gain is measured by the expected reduction of entropy $E(i)$ for the given set of attributes A_i and their values $v_n(i)$.

Due to desirability function $D(x)$ which is intuitively included in the model as intrinsic knowledge (decision makers only estimate comparative relations between values for each set of attribute) heuristics of the original method is modified to fit the preferences of the decision makers.

DoctuS Expert System Shell implements the described modified ID3 algorithm and allows for analysis of the informativity of the decision attributes in accordance to decision makers' preferences [4]. It enables consideration of a great number of attributes that may affect the final outcome of decision making process. Proposed solutions may include complex relations between the attributes originating from a number of knowledge domains i.e. interdisciplinary problems.

This is why DoctuS can be used to enhance understanding of the problem between experts in different domains of knowledge and provide unbiased insight in the decision making process.

4 Case Study

4.1 Evaluating IT Security Solutions

Investing in IT has always been one of most controversial issues for management executives. Often these investments are treated as costs due to the inability to adequately predict and measure their benefits on company performance. Despite contradicting results of recent surveys about the influence of investment in IT [2] [11] [12], information systems (IS) of companies have become highly dependant on information and communication technology (ICT) [19]. This is why security issues have become the primal concern of the information officers and managing executives.

According to the third annual information security survey conducted by Information Week and Ernst & Young, nearly half of more than 1,290 respondents representing information systems chiefs and security managers suffered security-related financial losses in the past two years [13]. Most companies hesitate to develop a structured and detailed disaster recovery plan (DRP) or security policies until a security incident arises. According to another survey [14], only 85 per

cent of the Fortune 1,000 companies had disaster recovery plans a decade ago.

This is why Hawkins et al [6] suggest a framework of disaster recovery planning (DRP) consisting of three functional areas: management, information technology and human resources. Here the selection of anti-virus software is an imperative for protecting the data contained in company LAN as well as regular and timely sweeps in order to ensure system integrity at all times.

One of the most important security issues in e-business are program intrusions by programmes specially developed for this purpose – *malware*. Threats from a software security breach could range from the very mild to disastrous while not being noticed at the time of occurrence [1]. The *malware* problem has spread so rapidly that it has created an industry to counter it and try to keep businesses clean of infection – the anti-virus industry.

The anti-virus solutions market contains a great number of products that address some or all *malware*-related security issues in a variety of degrees and success. This is the result of a fierce competition between brands for larger market shares, but it also makes the decision about choosing a brand more complicated for company executives.

There is also a number of specific parameters that need to be taken into consideration by the managing executives when making decisions about improving or maintaining the security of the IS. Costs that should be considered, are not only monetary amounts of implementation and support but also costs of functionality of the overall information system after the security solution is implemented. On the other hand, the estimation of the adequacy of the 'out-of-the-box' solutions is prone to error because it is highly dependent of the current organization of the enterprise and subjective.

Decision making about adequate security software should be supported by IT in order not only to allow unbiased comparison of different solutions but also to enable the managing executives to get a clearer picture of the criteria and their relevance on the final outcome.

Most of the relevant features of these *anti-malware* solutions are qualitative and thus hardly comparable between different brands. Other, quantitative features such as ratios and percentages may be misleading if compared across brands due to the differences in calculation methods used.

In order to avoid these pitfalls for decision makers and to support decision-making process an information-driven approach is used. In this way the need to convert qualitative sets of properties into quantitative measures of performance is eliminated so no additional and false information is incorporated in the decision making process. This allows for better modelling of the problem at hand thus enabling reaching a better decision.

4.2 Knowledge base model

For the purpose of supporting the decision on choice of available *anti-malware* software solutions, a knowledge base model was produced in collaboration with the IT security experts, users of the IS and management.

The produced model was derived according to the technical specifications for 10 leading *anti-malware* software solutions available. These specifications yielded 53 different decision attributes with at least two values. Some of these attributes are shown in Fig. 1. Values of all attributes are order form the most undesirable towards most desirable ones, according to expert knowledge. A special attribute that contains the final outcome of the decision process is called decision attribute and for the purpose of this analysis it is called '*Score*'. It represents the suitability of a particular *anti-malware* solution. The most unfavourable value is '*unrecommended*', intermediate values are '*sufficient*' and *'recommended*' and the most favourable value is '*outstanding*'. Similarly all of the other attributes are defined in the Attributes section of the DoctuS knowledge base (Fig. 1).

Attributes | Cases | Rule Based Graph | Rules of Score | Case Based Graph

Name	Value 1	Value 2	Value 3	Value 4
Score	Unrecommended	Sufficient	Recommended	Outstanding
Update Options	insufficient	good	outstanding	
File Scanning	insufficient	good	outstanding	
Technical Characteristics	insufficient	good	outstanding	
Update Features	insufficient	good	outstanding	
Scan Options	insufficient	good	outstanding	
Scan Scope	insufficient	good	outstanding	
Definition Updates	insufficient	good	outstanding	
Technical Support	insufficient	good	outstanding	
OS Support	insufficient	good	outstanding	
Certifications	insufficient	good	outstanding	
Scan Reporting	insufficient	good	outstanding	
Scanning Methods	insufficient	good	outstanding	
Cleaning	insufficient	good	outstanding	
Additional Scanning	insufficient	good	outstanding	
64-bit OS Support	insufficient	good	outstanding	
32-bit OS Support	insufficient	good	outstanding	
ISA 2005	no	yes		
WB100% 2005	no	yes		
W.C.L Level 1	no	yes		
W.C.L Level 2	no	yes		
Online Virus Scanner	not available	available		
Estimated Scan Time	not available	available		
History/Report Logging	not available	available		
Outbreak Notice	not available	available		
Automatic Definition Updates	not available	available		
Automatic Program Updates	not available	available		
Manual Definition Updates	not available	available		
Manual Program Updates	not available	available		
On-acess Scanning	not provided	provided		
Realtime Scanning	not provided	provided		
Scheduled Scanning	not provided	provided		
Heuristic Scanning	not provided	provided		
Manual Scanning	not provided	provided		
Adaware/Spyware Scanning	not provided	provided		
Script Blocking	not available	available		
Scan Compresssed Files	not provided	provided		
Auto-Clean Files	not available	available		
Quarantine Files	not available	available		
Email-POP3 Protection	not provided	provided		
P2P/File Sharing Protection	not provided	provided		
Registry Startup Protection	not provided	provided		
WebMail Protection	not provided	provided		
Live Chat	no	yes		
Phone Support	not available	available		
Manual/FAQ/Knowlage Base	not available	available		
User Form	no	yes		
Windows XP	not supported	supported		
Windows 2000/2003	not supported	supported		
Windows ME	not supported	supported		
Windows NT	not supported	supported		
Windows 98	not supported	supported		
Windows 95	not supported	supported		

Figure 1. Decision Attributes Table with attribute values

After most of the attributes that seemed relevant were introduced into the knowledge model, their interconnections and interdependencies were defined using Rule-based graph (Fig.2).

This graph is used to define the immediate interdependencies between attributes. On the left-hand side of the Fig. 2. there is the decision attribute '*Score*'. Its value is determined by the values of attributes '*Update Options*', '*File Scanning*' and '*Technical Characteristic*'. For each of these, a separate set of attributes that affect their values was defined on the next level of the rule-based graph. This was an iterative process known as knowledge extraction, and it involved a number of interviews with experts. Also it involved merging different parts of the tree because each segment of the tree referred to different expert domains. I.e. users of the system were concerned with availability of technical support while IT experts were concerned with channels of definition updates, for example.

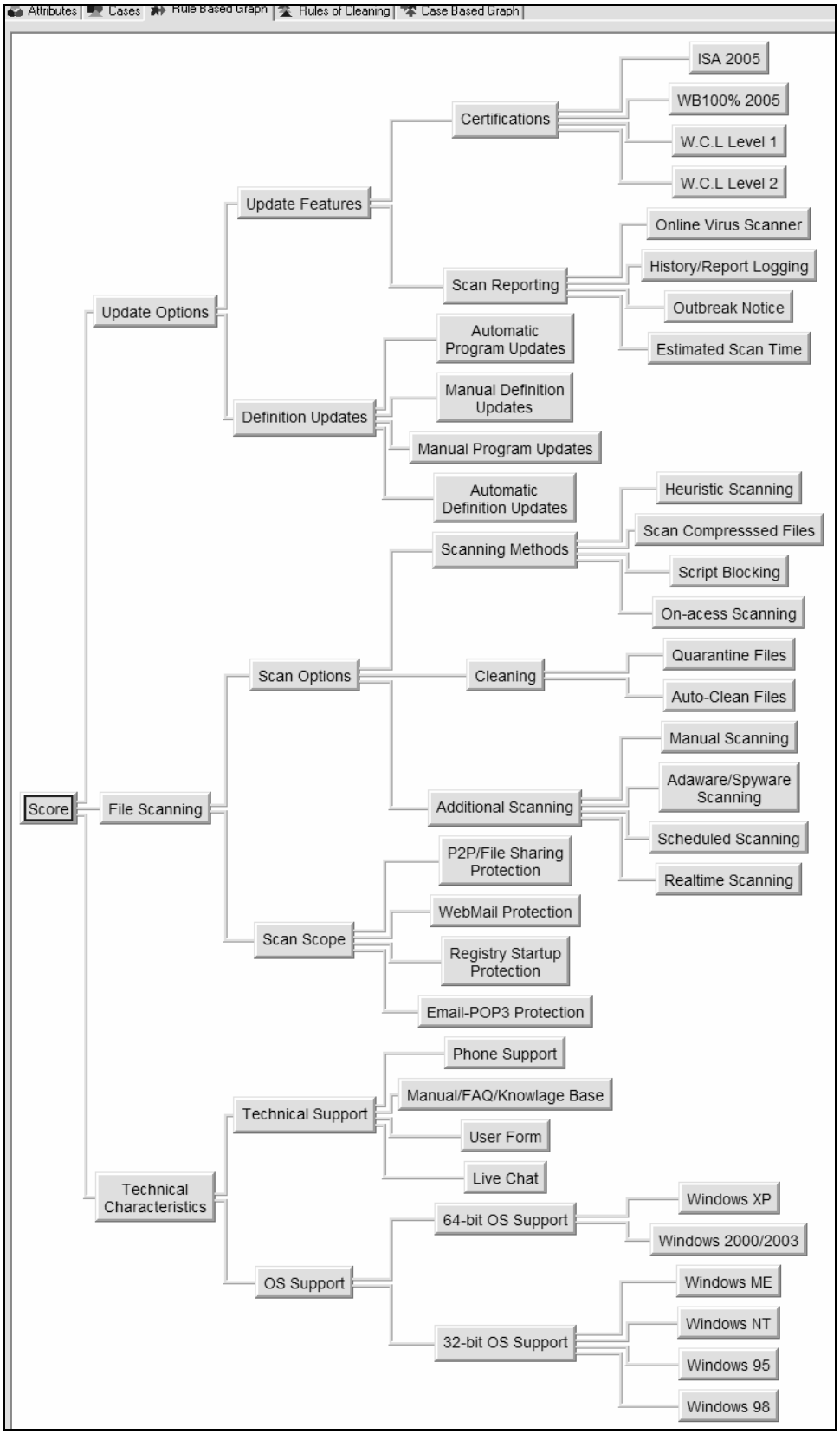

Figure 2. Rule-based graph

During the modelling of the rule-based graph some additional attributes were added to the knowledge base (such as available certifications shown in the right upper corner of the rule-based graph in Figure 2, etc…).

When the rule-based graph was finished rules for all of the dependant attributes needed to be defined. These rules specify in what way is the dependant attribute affected by different combination of values of the bound attributes. All combinations of values of bound attributes can be presented in the form of a grid - 2D view (Fig. 3).

	Update Opti	insufficient	good	outstanding
File Scannin	Technical Cl			
insufficient	insufficient	Unrecommended	Unrecommended	Unrecommended
insufficient	good	Unrecommended	Unrecommended	Unrecommended
insufficient	outstanding	Unrecommended	Unrecommended	Unrecommended
good	insufficient	Unrecommended	Unrecommended	Unrecommended
good	good	Unrecommended	Sufficient	Sufficient
good	outstanding	Unrecommended	Sufficient	Sufficient
outstanding	insufficient	Unrecommended	Unrecommended	Unrecommended
outstanding	good	Unrecommended	Recommended	Recommended
outstanding	outstanding	Unrecommended	Recommended	Outstanding

Figure 3. 2D View of the rules for decision attribute *'Score'*

In Fig. 3 rules for decision attribute *'Score'* are shown. In the headers of rows and columns there are all of the combinations of bound attributes' values. In the centre of the table at every intersection of rows and columns there is a cell with an outcome of the decision for each combination of affecting attributes. For example, the *'Score'* will be *'outstanding'* only if *'Update Options'*, *'File Scanning'* and *'Technical Characteristics'* are also evaluated as '*outstanding'*.

Due to the desirability function D used for defining the order of attribute values all defined rules can be checked for inconsistencies. For each pair of rules R_1 and R_2 values v of bound attributes A_i must be ordered in the same way as the desirability of decision attribute values v:

$$\forall[R_1,R_2]: \{D(v(R_1)) \leq D(v(R_2)): \quad D(v(A_i)) \leq D(v(A_j)), i \neq j, \forall i=1,2,..n, \ \forall j=1,2,...n\}.$$

After all of the rules are included in the knowledge base and after all of the consistency issues are resolved, the knowledge base is prepared for consultation and testing. For this purpose a training set of example cases is used. These examples represent different IT security solution brands. For each brand input attributes (shown in Fig. 2. as leaf nodes of the rule-based graph) are added in 'Cases' section of the knowledge base.

Decision attributes are derived by the system using knowledge model by activating 'Reason' function. The results are given in Fig. 4.

5 Discussion

All of the used example cases yielded evaluation scores at least *'sufficient'* and none returned *'unrecommended'* value. This is due to the fact that only top 10 commercially available brands were used.

In order to differentiate between the brands a case-based graph can be created from defined example cases. Since case-based graph is induced using ID3 algorithm, only most informative attributes are used to classify given cases. A list of attributes with highest measures of information gain are presented in Fig. 5. These attributes represent the only significant factors that may differentiate evaluated brands. As we can see from the Case-based graph shown in Fig. 6 the availability of script blocking feature in combination with Windows NT support and ISA 2005 Certification makes a distinction between outstanding solutions and the rest, according to the model of expert knowledge of the consulted specialists.

Another advantage is the capability of the model to provide the whole picture of the decision process without inconsistencies. It can be used to generate explicit explanations why some products are better than the others.

Attributes | Cases | Rule Based Graph | Rules of Score | Case Based Graph

	Bit Defende	Kaspersky	F-Secure 2006	PC-cillin 2006	Eset NOD32	McAfee 2007	Norton 2007	AVGPro 7	CA AV 8.	Norman 5
Score	Outstanding	Outstanding	Recommended	Recommended	Outstanding	Recommended	Recommended	Sufficient	Sufficient	Sufficient
ISA 2005	yes	yes	no	yes	yes	yes	yes	yes	yes	yes
WB100% 2005	yes	yes	yes	no	yes	yes	yes	yes	yes	yes
W.C.L Level 1	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
W.C.L Level 2	yes	yes	yes	yes	yes	yes	yes	no	yes	yes
Online Virus Scanner	available	available	not available	available	not available	not available	not available	not availa	available	not availat
Estimated Scan Time	available	available	not available	not available	not available	not available	not available	not availa	not availa	not availat
History/Report Logging	available	available	available	available	available	available	available	not availa	available	available
Outbreak Notice	available	available	available	available	available	available	available	available	available	available
Automatic Definition Updates	available	available	available	available	available	available	available	available	available	available
Automatic Program Updates	available	available	available	available	available	available	not available	not availa	available	available
Manual Definition Updates	available	available	available	available	available	available	available	available	available	available
Manual Program Updates	available	available	available	available	available	available	available	not availa	available	available
On-acess Scanning	provided	provided	provided	provided	provided	provided	provided	provided	provided	provided
Realtime Scanning	provided	provided	provided	provided	provided	provided	provided	provided	provided	provided
Scheduled Scanning	provided	provided	provided	provided	provided	provided	provided	provided	provided	provided
Heuristic Scanning	provided	provided	provided	provided	provided	provided	provided	provided	provided	provided
Manual Scanning	provided	provided	provided	provided	provided	provided	provided	provided	provided	provided
Adaware/Spyware Scanning	provided	provided	provided	provided	provided	provided	provided	provided	not provic	provided
Script Blocking	available	available	available	available	available	available	available	not availa	not availa	not availat
Scan Compresssed Files	provided	provided	provided	provided	provided	provided	provided	provided	provided	provided
Auto-Clean Files	available	available	available	available	available	available	available	available	available	available
Quarantine Files	available	available	available	available	available	available	available	available	available	available
Email-POP3 Protection	provided	provided	provided	provided	provided	provided	provided	provided	provided	provided
P2P/File Sharing Protection	provided	provided	not provided	not provided	not provided	not provided	not provided	not provic	not provic	not provide
Registry Startup Protection	provided	not provide	provided	not provided	not provided	not provided	not provided	not provic	not provic	not provide
WebMail Protection	not provide	not provide	not provided	provided	not provided	not provided	not provided	provided	not provic	not provide
Live Chat	yes	no	no	no	no	no	no	no	yes	no
Phone Support	available	available	available	available	not available	available	not available	not availa	not availa	available
Manual/FAQ/Knowlage Base	available	available	available	available	available	available	available	available	available	available
User Form	no	yes	no	no	no	no	no	no	no	yes
Windows XP	supported	supported	supported	supported	supported	supported	supported	supporte	supporte	supported
Windows 2000/2003	supported	supported	supported	supported	supported	supported	supported	supporte	supporte	supported
Windows ME	supported	supported	supported	supported	supported	supported	not supported	supporte	supporte	supported
Windows NT	supported	supported	supported	not supported	supported	not supported	not supported	supporte	not supp	supported
Windows 98	supported	supported	supported	supported	supported	supported	not supported	supporte	supporte	supported
Windows 95	not supporte	not support	not supported	not supported	not supporte	not supported	not supported	supporte	not supp	supported

Figure 4. Cases Table with properties of 10 leading anti-malware software solutions

Informativity | Cases | Statistics

Attribute	Informativity	Density
Script Blocking	0.4406	5.61
Estimated Scan Time	0.2232	2.84
P2P/File Sharing Protection	0.2232	2.84
Windows 95	0.2232	2.84
Windows NT	0.1855	2.36
History/Report Logging	0.0968	1.23
Manual Program Updates	0.0968	1.23
Adaware/Spyware Scanning	0.0968	1.23
W.C.L Level 2	0.0968	1.23
Live Chat	0.0855	1.09
User Form	0.0855	1.09

Figure 5. List of most informative attributes for given set of cases

Figure 6. Case-based graph

Finally, knowledge base can be used for benchmarking dependant attributes to reveal interdependencies between different decision factors. In this way the knowledge of the experts can be enhanced as well as the understanding of different features and their influence on the decision making process.

Benchmarking between example cases using attribute *'OS Support'* revealed that the main concern for providing OS Support is the possibility of supporting Windows NT operating system (Fig. 7).

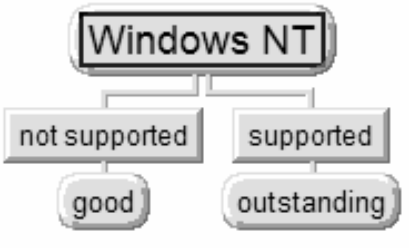

Figure 7. Benchmarking between cases (*anti-malware* solution brands) by *'OS Support'* attribute

Figure 8. Benchmarking between cases (*anti-malware* solution brands) by *'Scan Scope'* attribute

Benchmarking between example cases using attribute *'Scan Scope'* revealed that best solutions must provide at least registry start-up protection or webmail protection within their file scan options (Fig. 8).

6 Conclusion

Since the only certain source of lasting competitive advantage of companies is knowledge, transformation of the knowledge that can only be experienced (i.e. tacit knowledge) and not coded and learned (i.e. explicit knowledge) is of the highest importance for companies. Decision making process takes into account all of the available relevant knowledge in order to reach optimal decision, specifically knowledge that is not available to other competitors.

In this paper we proposed an information-driven approach that can be used to make model of knowledge that management executives and experts posses. This approach is based on the decision tree model that is induced using modified ID3 algorithm implemented in DoctuS Expert System Shell. The basis of the model is the model of expert knowledge acquired from the experts involved in the decision making process. Finalised model contains combined knowledge from all of the experts included in the decision process and therefore it has potential to reveal new relations that have not been explicitly articulated during the knowledge engineering process.

In this paper we also presented a case study where knowledge was used to determine the criteria for evaluation of various decision options during a selection of IT Security solution for the organisation. After the knowledge from all of the experts was codified and modelled, model was trained using actual data about top commercially available security brands. At the current level of sophistication of anti-malware solutions decision tree model revealed the properties that make the most significant diversification between tested brands. It was concluded that these features are: availability of script blocking, support of old OS systems and ISA 2005 certification. In this way the model reduced number of relations and revealed rules that were not explicitly articulated during the development of the knowledge base.

Finally, benchmarking other attributes provided explicit knowledge about different features of anti-malware solutions. First of all the main concern in providing OS support is that the solution provides support for Windows NT operating system. Also best brands provide either registry start-up protection or webmail protection within their scanning options.

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