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Abstract. The authors explore the issue of creativity support by computerized information systems used in supporting decision making processes in business organizations. A discussion of their architectural proposal for a creative decision support system, derived as an extension of the classical Sprague-Carlsson 1982 concept, is followed by a case study presenting a system at work being a practical implementation of their theoretical ideas. Their research is currently heading toward hybrid systems which, as the authors emphasize in the conclusion of their paper, appear to best suit their most immediate objectives in the study of creativity support.

Keywords: creativity support, decision support, system architecture, software agents, hybrid systems

1 Introduction

In his 2003 insightful paper on “Defining Decision Support Constructs” Power observes that “research scientists in academic settings pioneered many applied decision support technologies and now it is necessary to develop and test theories of decision support” [1]. It does seem to us that today the fundamental challenge faced by DSS research is not so much in advancing the deployment technology but, rather, in furthering decision support theory. Indeed, our research interests have recently shifted from the mere exploration of latest technology applications toward the investigation of DSS architectures and the decision making process itself. This paper largely reflects this shift, aiming to present the outcome of our most recent attempts to contribute to the DSS theory by developing, testing and validating a variety of potential DSS architectures. In that we admit to being also inspired by Arnott and Pervan [2] who insisted on improving the relevance of DSS research by increasing the number of case studies.

It is commonly agreed that modern DSS theory goes back to 1982 when Sprague and Carlson proposed the first mature DSS architecture. Their seminal concept distinguished three components [3]:

- the (analytical) model,
- the database,

- the human interface,

where the model would be supported by the database at input and by the human interface – at output [4]. Since then, the concept has underlain and fuelled a great deal of research and implementation efforts which either built on it or proposed its modifications and extensions.

The late 1990s saw meaningful enhancements to DSS theory from scientists researchers dealing with logical (rather than computational) transformations in the area of artificial intelligence. This added the capability of reasoning to the DSS functionality, and enabled it to provide advice on specific problems [5]. Further research led to the emergence of hybrid models, where a distinct discrete component is responsible for switching between models according to their prevalent competences. A bit earlier, the issue of an integrating component sprang up in the context of network technologies and Group DSS as they were entering a period of explosive growth (cf. e.g. [6] [1]. Considering the "cracks" identified in the DSS concept, and welcoming the increased availability of ideas and technologies supporting integration (CORBA, XML, J2EE), we proposed to extend the established DSS architecture by including a communication component which, among other advantages, would introduce a new dimension to system scalability.

However, as we reviewed multiple cases of a financial analyst's work supported by a system based on the extended data–dialog–modeling–communication paradigm, we were somewhat unsatisfied with the efficiency of the support, whether it was performed by artificial intelligence or, in a later variant, in line with the model of the rational decision making process [7]. At that point we assumed that it could be possible to achieve better results through the implementation of solutions developed in the area of creativity support, such as visualization techniques, idea generation and validation by a dedicated expert system, or brainstorming [8]. The limitations of the decision maker's bounded rationality, particularly strongly affecting partial decisions, will be overcome by providing support for the right brain hemisphere (parallel processing, tacit knowledge, double loop learning, intuition) and by switching between right brain and left brain. Thus we concluded that our experiences indicated the need to further extend the decision support system architecture by incorporating a creativity support component.

The classical components have also undergone transformation, being confronted with the more and more advanced technologies:

- The data component is rapidly evolving with technologies termed with such buzzwords as "Business Intelligence" or "Competitive Intelligence" (cf. Data-Driven DSS [1] [4]).
- The modeling component now encompasses, as it has already been mentioned, hybrid models and the increasingly popular Analytical Intelligence solutions.
- The dialog component is at the moment transiting from the metaphor-based dialog (i.e. relying on graphical representations of documents, desktops, dashboards, files) toward the incorporation of natural dialog founded on speech recognition and generation or gestures (handled by e.g. specialized interface agents).

All of the development work that supplied us with case studies and opportunities to test the proposed data–dialog–modeling–communication-creativity architecture were carried out by Consorg company. We owe it for most findings described or referenced in this paper.

2. A Creative DSS Architecture

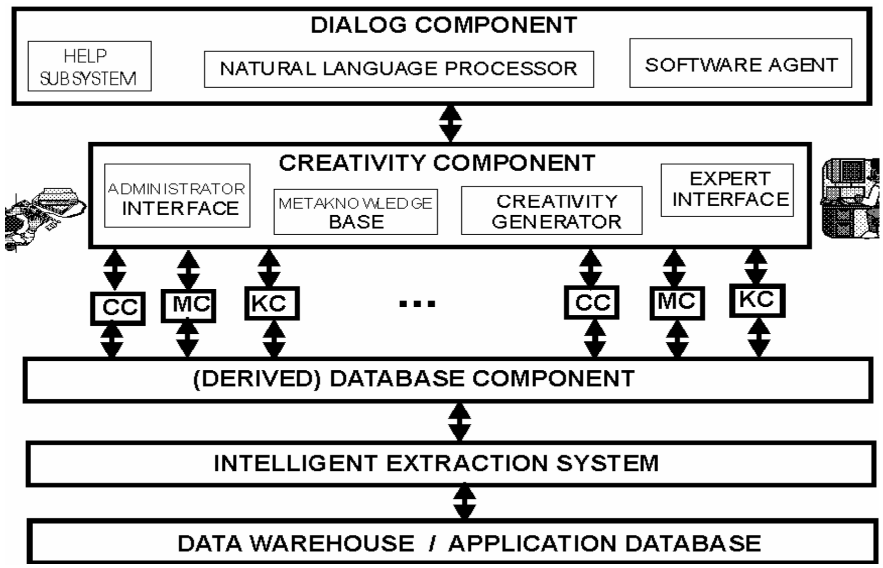

Fig. 1. Creative decision support system architecture [9]. *CC* stands for *Communication component*; *MC – Modeling component*; *KC – Knowledge component*

Artificial intelligence is the science of machines performing tasks that involve intelligence when performed by humans. Propositions regarding the DSS architecture were presented by Sprague and Carlson (cf. [3]) who framed the data–dialog–modeling paradigm, one which has been truly germinal to the contemporary DSS concepts. The current rapid progress of information technology and methodology seems to entail an extension of this paradigm through the inclusion of a communication component and a creativity component (cf. Fig. 1).

The following chapter discusses a creative DSS architecture which emerged from our work on the implementation of the extended paradigm.

2.1 Communication component

As there is no way of predicting all the user's future expectations or the technologies needed to satisfy these expectations, a hybrid artificial intelligence system architecture should be as open as possible and should be composed of largely independent components. The software agent approach was used to meet this demand – the particular components of the hybrid system are agents performing autonomous tasks. Each agent constitutes a system on its own, although it may depend on other agents for some of its operations. Similarly, different tools may used to develop each specific element. On the other hand, hybrid artificial intelligence systems – much like analytical platforms – involve the use of a separate tool to define their fields of operation, to enable interchange of facts and knowledge, and to facilitate communication with their less direct environment. Therefore, a special environment for the development of distributed architecture hybrid multi-agent artificial intelligence systems was created. Since hybrid systems of this sort are designed to address specific problems, we could actually speak of developing specialized team agents [10].

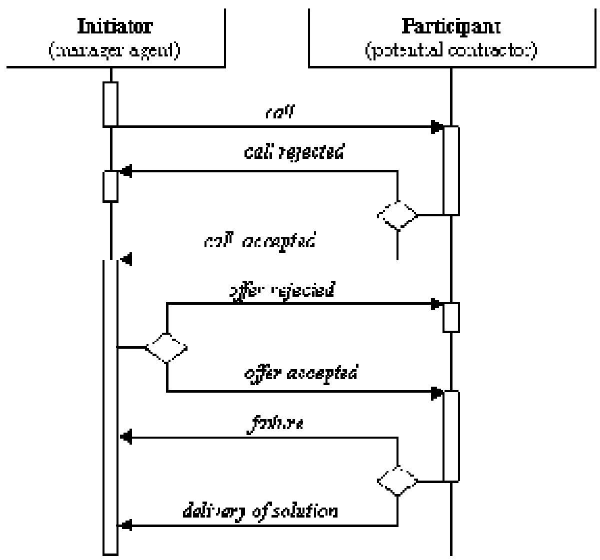

Fig. 2. The operating principle of the Contract Net protocol, drawing on the FIPA Contract Net Interaction Protocol.

In a highly diverse environment, it is critical to ensure adequate coordination so that the agent team works in concert toward the achievement of the primary objective. A number of protocols are known describing agent interactions. The so called blackboard systems appear to be in best accord with the idea of team-work and concerted task performance. Within these systems, each agent (team member) records its subsequent steps on a blackboard (based on the information which has already been written up) until the final solution is found. However, the distributed structure of blackboard systems would be difficult to implement in our case due to the need to share resources. Instead, we have chosen to apply the Contract Net protocol, which is ideally suited to the development of distributed systems and at the same time accommodates the team-work of agents as they cooperate in executing their individual tasks and contributing toward the achievement of the main objective [11]. The protocol includes a specialized manager agent which initiates the process and identifies potential contractors – solution providers – thus taking responsibility for the interactions among the agents (Fig. 2).

Any one of the agents may become a manager at any given time. The agent's role depends on whether it is performing tasks contracted by another agent or whether it has to contract a task from an agent to be able to perform its own task. A disadvantage of using the Contract Net protocol is in the probability of choosing an non-optimal agent to perform a contracted task (there is no negotiation process built in – the first agent to give a positive response to the call will perform the task). There is also some likelihood that the main objective will not be achieved, in case a potential solution provider rejects the call, being busy with other tasks. To at least partially eliminate these shortcomings, as well as to enhance the system's efficiency and reduce the workload per agent, simple learning mechanisms have been introduced. As a result, the system matures throughout its life, as the agents learn to find the best contractors in each situation (thus they do not need to send calls to all team members) – they will evaluate the other agents in terms of their ability to solve a particular class of problems (they can even reject solution proposals received from agents that are not recognized as optimum contractors in a particular situation).

2.2 Data component

This component's architecture is founded on an analytical platform making up an integrated application development environment incorporating OLAP technology and expert knowledge bases (cf. e.g. [12] [13]), as illustrated in Fig.3.

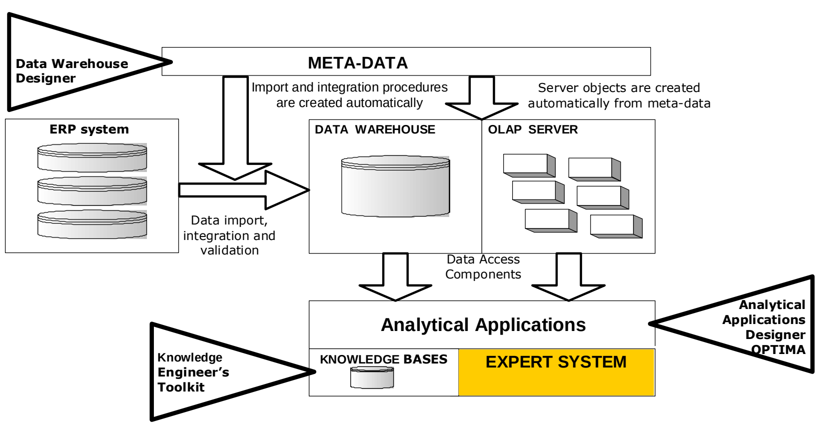

Fig. 3. The analytical platform of the Optima Controlling system as an architectural component of a creative decision support system [16].

The expert system represents a central element of the component's architecture, performing three fundamental functions:

- diagnosis – using a set of observable symptoms to determine the current state of the enterprise (as well as identifying weak signals e.g. from the environment);
- construction – creating detailed user reports based on the diagnosis performed;
- control – controlling the application by monitoring the user's activities and triggering appropriate actions depending on the current context of analysis (e.g. customizing report generation, executing data transformation scripts).

Input data, depending on the requested level of generalization (operating level or strategic level) are provided by [14]:

- transaction systems – directly from the data bases and/or from alarms generated by procedures monitoring the changes that take place in the databases (the so-called triggering subsystem [15]; or
- data warehouses – where qualitative data and pre-defined quantitative data aggregates stored within OLAP cubes allow the generation of warning signals related to the performance of the strategic goal being monitored.

2.3 Modeling component

Each of the leading artificial intelligence technologies exhibits some strengths or weaknesses depending on the application context [17]. Literature supplies many examples of successful applications based on an artificial intelligence technology hybridization paradigm [18] [19]. In addition, hybridization may be regarded from the viewpoint of the relationships between the database platform and the data processing technologies used. This approach substantially extends the area in which to search for component combinations to apply in addressing a problem, bringing us closer to the selection of the best solution. The power of OLAP technology to help identify cause-and-effect chains by manipulating quantitative data means that it can provide effective support for strategic processes in organizations. The most promising business results are achieved through its integration with MRP/ERP class systems [12]. On the other hand, some artificial intelligence components, such as expert systems or fuzzy logic systems, can handle qualitative (symbolic) data.

It seems that aligning the strengths of OLAP technology with artificial intelligence components that support symbolic data processing will make it possible to build a technology platform capable of effectively tackling decision processes at strategic level. It is probably a commonplace to say that efficient application of artificial intelligence involves the use of such a combination of leading-edge technologies that will produce optimum synergy. Over the years, the authors have been able to tentatively validate the effectiveness of a number of artificial intelligence applications representing the most common types: expert systems (ES), fuzzy logic (FL) systems, genetic algorithms (GA) systems, case based reasoning (CBR) systems, and artificial neural networks (ANN). For example, the following hybrids have been considered and examined for stand-alone, tight-coupling and full-integration solutions:

- ES – FL – GA – OLAP – RDBMS,
- FL – CBR – GA – OLAP – RDBMS,
- CBR – FL – ANN – OLAP.

It should be observed that intelligent hybrid objects emerging from the synthesis are all linked to database platforms. The A-S-C (analyzer-simulator-communicator) research model, employed by the authors several years ago and later discussed in [14], was found to provide an effective framework for the linkage.

2.4 Dialog component

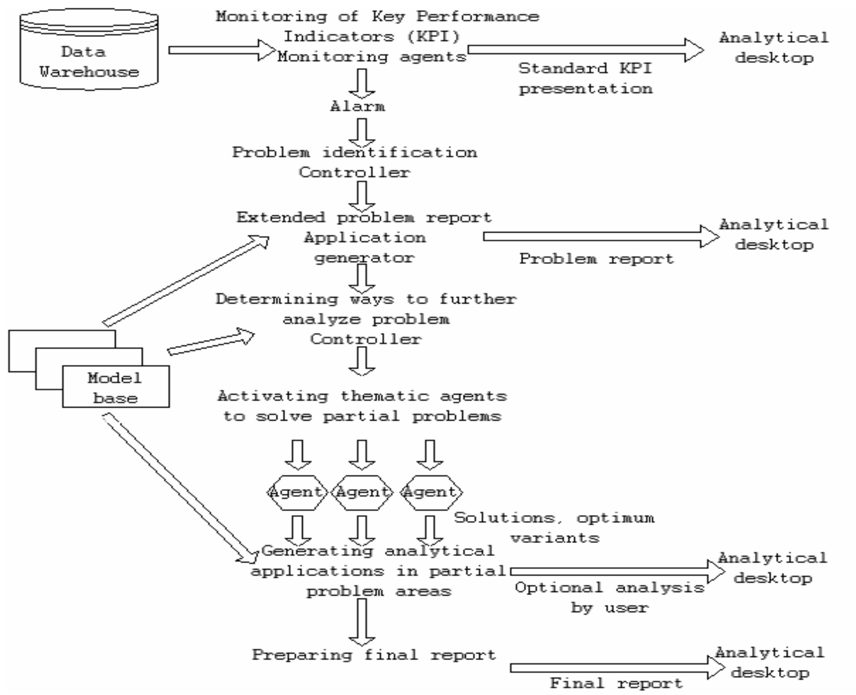

Fig. 4. The analytical process within the framework of OSS development [20].

Fig. 4 demonstrates the general functional scheme of a multi-agent architecture. The data warehouse is the key information source for all components involved in the process. However, each of the agents has the autonomy to look for the required information in any available alternative resources (ERP system data bases, other dedicated record applications, documents, spreadsheets, the Internet). The analytical desktop, implemented as an interface agent operating in an intranet or Internet environment, is the preferred interface solution allowing access to analysis findings and to reports generated.

2.5 Creativity component

As part of objective finding, the so called key performance indicators (KPI) are sought, which are the facts constituting the original causes (sources) of the current state of the object being diagnosed – i.e. the financial condition of the enterprise. It is assumed that discovering these facts will provide the basis on which the actual diagnostic problem can be formulated. The fact finding process employs data mining technologies to query the multi-dimensional OLAP data bases. The classical ad hoc drill-down search is supported by an expert system. The expert system's inference process governs the drilling toward the discovery of relevant facts. This means that the formulation of a drill-down query depends on the conclusion produced by the expert system. The query result then fires another sequence of rules which will trigger a further drill-down query. The process terminates in case the expert system is unable to generate a conclusion and, consequently, activate another query. The objective finding should take place through discovering the underlying cause-and-effect chains among the increasingly more detailed information sets delivered in the query reports.

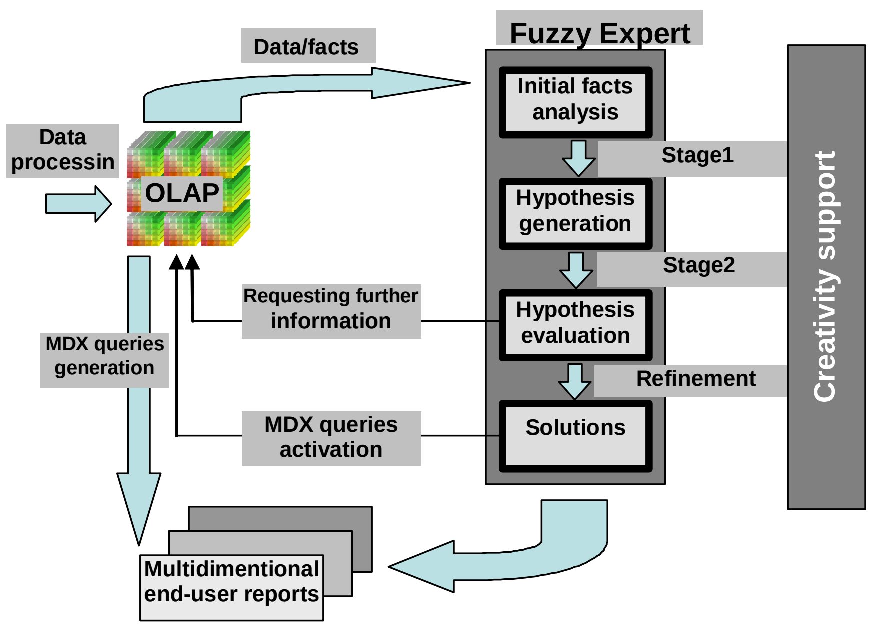

Fig. 5. The strategy of multidimensional problem solving method, eFuzzyControlling system [13].

Within the proposed approach, solutions to diagnostic problems are searched by generating and validating different sets of hypotheses (scenarios). The validation process relies on the monitoring of a range of the so called risk signals, i.e. key performance indicators identified for each area being examined. Hypotheses, taking the form of likely decision-making scenarios, are generated by the expert system and derived from the financial analyst's interactive queries to the multi-dimensional

OLAP bases and knowledge bases (Fig. 5). As a result, a given set of hypothesis is broken down into opportunities and threats, with a weight attached to each of them indicating its relevance. An opportunities and threats analysis, which is subsequently performed within each area of the enterprises' activity, focuses our attention on the most significant opportunities and threats, reducing the set of hypotheses to an extent where we are left with just those most promising ones. An assumption has been made that, as Proctor [21] has it, the sole realization that there exist different views on the same subject may give rise to an exchange of opinion and elicit new ideas". Therefore, the ensuing solution finding procedure encompasses all combinations of opportunities and threats that have been recognized as significant. The procedure aims to reconstruct the perception of the issue under consideration and then use the opportunities and threats combinations to develop a viable solution (ideas).

Each of the conclusions is backed up with the underlying sequence of the expert system's knowledge base rules that have been fired. In case contradictions are detected, they will be typically attributable to varying interpretations of facts reflecting the diverse perceptions of the knowledge providers who have fed the expert system. In investigating the contradictions (by tracing the explanations) the user should be encouraged to formulate and test a number of hypotheses. There are two types of potential contradictions that will call for a critical review of the diagnostic problem: one of them occurs when the expert system returns varying conclusions for the same factual body, while the other arises when identical conclusions are coupled with different explanations. Within the proposed approach the issue of keeping the knowledge stored in the expert system up to date does not figure much, as new knowledge extends, or supplements, the existing resource rather than replaces any portion of it, in this way opening up a new perspective on the problem. The analytical phase thus finally produces an open set of tentative (and sometimes incompatible) solutions to the problem.

At the evaluation phase, the solutions are ranked against the objectives. The basic evaluation criteria laid down by P. Drucker are used: risk, effort, time and resources. Special emphasis is placed on the possibility to test the idea in "a safe environment" before the final evaluation is made. To this end, support tools have been implemented, such a: simulation models, sensitivity analysis and business simulators (strategic decision making games). The best solutions are expected to make up a coherent scenario that fully elucidates the problem. These solutions are included into a separate knowledge base (known cases base), which is regarded as a complementary knowledge resource for use in creative solution finding with future diagnostic problems.

3. Creative Problem Solving Support – A Sample Decision Making Scenario

3.1 Initiating a decision making session

The initiation procedure aims to identify the company's strengths and weaknesses (in the example, attention will be focused on the assessment of its financial position), as a preparatory step for a fundamental analysis of the company. It is assumed that the complete analytical procedure followed by a technical analysis of the company's stock will produce a resource of information sufficient to make an informed decision on purchasing or selling the stock.

The sample diagnosis was produced for a company listed at the Warsaw Stock Exchange. We conducted an analysis of the company's performance over the period 2001-2004. We did not use any information other than that made publicly available within the stock exchange reporting requirements or published in the issue prospectus. A review of the company's strategic position reveals emerging problems in the area of finance management while the company is still able to retain a firm competitive position and a strong technology advantage. Guidelines for further examination will be provided by risk signals observed in the particular areas of finance management. The initial diagnostic objective might then be *to evaluate the perceived trends in the area of financial liquidity and profit capacity in order to see if they might point to a decline in the enterprise's financial condition*.

3.2 Problem finding (identification)

The objective finding procedure results in a set of hypotheses (diagnosing the decision problem) along with explanations (conclusions from the expert system) designated as opportunities and threats (Table 1). By organizing the hypotheses into a hierarchy and analyzing their value system we move toward the final definition of the diagnostic problem.

The analytical phase of the creative problem solving process leads to a precise definition of the diagnostic problem. In the case we are studying, based on the information on the most significant opportunities and threats, the actual diagnostic problem was formulated as follows:

- *How does the company maintain a high level of financial liquidity in case a considerable decrease of sales revenues is accompanied by an increase of short-term liabilities?*
- *How long will the company be able to keep a safe level of working capital in case its net profit continues to decrease?*

Table 1. A sample set of hypotheses for a diagnostic problem, classified as opportunities and threats.

	STRENGTHS		WEAKNESSES	
1	High level of cash flow	0.40	Large decrease of sales revenues	0.45
2	High level of working capital	0.20	Decrease of net profit	0.25
3	Low level of debt	0.15	Increase of debt payable	0.20
4	High flexibility of liabilities	0.10	Increase of current liabilities due	0.07
5	Financial profit	0.15	Increase of reserves to cover liabilities	0.03
		1.00		1.00

3.3 Initial solution finding

Further examination primarily aims to verify the opportunities and threats relating to (cf. Table 1):

- financing through working capital (a drop in revenues is signaled),
- liquidity of current assets (an increase in receivables has been perceived),
- flexibility of current liabilities (a contradiction is detected),
- safety margin for operating activities (a decrease in profit is flagged off).

The examination of the first two areas does not provide the answers we look for. An analysis of the next area – flexibility of current liabilities – does yield some ideas, however. The combination of opportunities and threats found in this area appears to be self-contradictory (Table 1):

"increased flexibility of liabilities – 0.15 " <=> *"an increase in current liabilities due – 0.07"*

This clearly indicates the need to identify the reasons (facts) fed into the inference process and to critically re-examine the ways in which the conclusions were reached. More in-depth explanations should be sought in the other areas of finance management, namely in operating profit capacity, where net profit is only sustained owing to a substantial reduction of fixed costs in relation to sales revenues. The liabilities structure shows similar stability due to a safe relation between debt and receivables. Nevertheless, the safety margin approximates the zero, which indicates a firm barrier to further decrease in sales.

3.4 Intuitive phase

Within our approach, the intervention of the creative decision support system is, at this stage of the process, limited to enabling a multi-dimensional, multimedia-based presentation (Fig. 6) of the preliminary solutions generated at the analytical phase. The use of varied presentation techniques and layouts is supposed to help the user get a broad overview of the problem and grasp it in all of its aspects. As a result, a set of problem solutions (ideas for resolving the problem) should be elaborated.

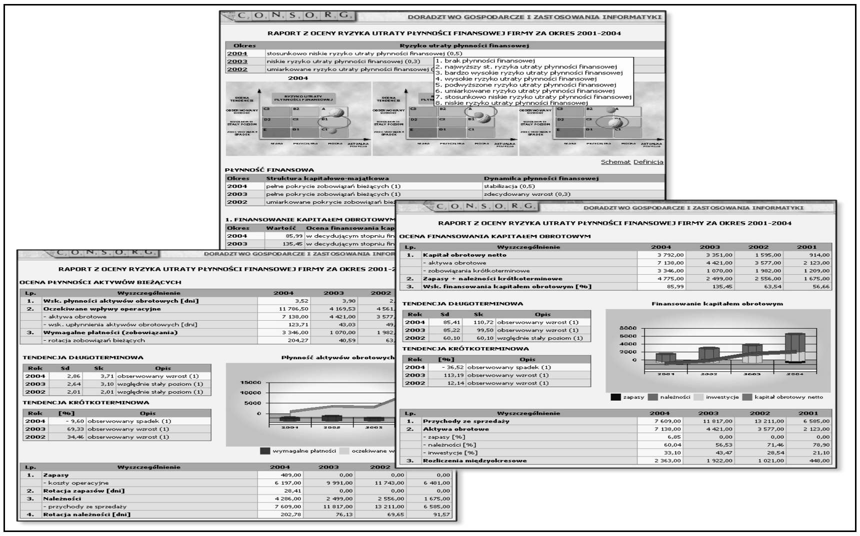

Fig.6. A diagnostic report on the DGA S.A. company's financial positions (eFuzzyControlling system).

3.5 Critical phase

First of all, a report is generated highlighting the most "promising" solution scenarios. The final validation is left to the discretion of an analyst, who takes advantage of the system's interactive support in formulating and justifying the diagnosis.

By way of summary, it should be stated that the analysis of DGA S.A. company carried out with the use of the creative decision support system, has not revealed any symptoms that could threaten its financial liquidity in the short term. The strong correlation between operating cost structure and sales revenues ensures that the company can safely manipulate its profit and its liabilities, despite substantial fluctuations in sales. In the long run, however, a continued decrease in sales might bring the company below the break-even point, which will result in a rather rapid loss of financial liquidity.

4. Conclusions

In undertaking the research on the data-dialog-modeling-communication-creativity architecture we hoped to devise a useful framework within which to develop decision support systems that could truly rise to today's challenges, needs and expectations. This paper presents a summary of the authors' implementation work done within the consulting firm Consorg aiming to verify the applicability of the proposed architectures in an effort to contribute to the progress of decision support theory and methodology. This ambition reflects our recent commitment to what we believe is the primary challenge for contemporary DSS research.

The work on computer-based decision support systems conducted within a number of organizations (e.g. Południowy Koncern Energetyczny S.A. [Southern Power Corporation], Agencja Rozwoju Przemysłu S.A. [Industrial Development Agency], Vattenfall Heat Poland S.A. [8]) has strengthened the authors' belief in the viability of hybrid solutions and encouraged them to continue researching these within the framework of the data-dialog-modeling-communication-creativity architecture representing a proposed extension of the classical Sprague-Carlson concept. The most effective solutions elaborated by Consorg would combine an ERP system, a data warehouse and a decision support system consisting of Analyzer, Simulator and Communicator components. What we have found particularly promising about them is that they showed a degree of flexibility which makes it possible to apply them to different classes of problems and to suit them to the needs of different types of organizations.

A close observation of the decision making process by a financial analyst uncovered relationships between analytical operations and holistic operations, e.g. where the analyst, with all his fluency in ratio analysis (partly due to support by an expert system), could not timely provide the criteria for further actions and got stuck without much prospect for a solution. With that sort of difficulty, the only way to advance decision support seems to address support at creativity.

The prototype integrated creative decision support system described in this paper was aimed at supporting the creative decision making process at the stages of problem finding, fact finding, problem definition, idea generation, idea elaboration and idea evaluation. It has been developed on the basis of components available within an intelligent, multi-dimensional analytical environment. The potential applications of OLAP technology and intelligent systems are many; by integrating the two we produce a kind of synergy which results in new possibilities to apply the proposed approach. Explicit knowledge representation which is available to the user during the inference process performed by an expert system becomes a unique tool supporting the creative decision making process.

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