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Development and Investigation of Multi-Agent Expert Investment Decision Support System

Summary of Doctoral Dissertation
Technological Sciences, Informatics Engineering (07T)

2014, Kaunas

Kaunas University of Technology

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DEVELOPMENT AND INVESTIGATION OF MULTI-AGENT EXPERT INVESTMENT DECISION SUPPORT SYSTEM

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INTRODUCTION

Definition of the problem

Rapid development of information-oriented society and its environment launches a lot of challenges in finance and investment management sphere. World financial markets have become easily accessible for investors from all over the world owing to modern information technologies. Easy access to world financial markets has encouraged the growing of the investor society, which in its turn exerts strong influence on world economic development. Modern investors are displeased only with the opportunity of easy access to financial markets, they need information and knowledge. Having easily reached financial markets investors directly face the difficulty of information processing and management, i.e. financial markets are distinguished for rapidly changing information environment. With plenty of such information at hand both individual and institutional investors experience difficulties covering such huge amount of information. Even having coped with plenty of information there is still a very challenging task left to obtain knowledge from it. Financial markets is a place where the obtaining of knowledge from information present at financial markets must take place in real time and quickly. Time is very important for investment success.

Raised issues are of practical nature, and their settlement must involve different scientific knowledge such as economics, financial management, mathematics, information technologies etc. In summary it can be said that modern investors need all-in-one solution (combining the management of both information and knowledge) which can simplify their orientation in financial markets and could be implemented through the medium of modern investment management or investment decision support information system. In such a way work problematic comes down to the creation of investment decision information system.

Topicality of the research

Nowadays in order to invest, to trade and to speculate at financial markets successfully it is insufficiently only to be sound on fundamental, technical or other methods of securities assessment and portfolio management. Today, when the trade of securities has moved into the internet environment investors face new challenges.

First of all, financial markets have become global, i.e. on the one hand, it has become very easy for investors to make investments in any world region, but on the other hand, they face a need to be sound on the specific character of each corresponding region, adapt to it and learn to work there. Secondly, financial markets have become dynamic, i.e. they can quickly change directions, thus there is a need to follow information continuously, to analyse it, to draw immediate conclusions and make investment decisions on the ground of them. Consequently,

investment management is rather complex and multipronged task. Naturally appears a need to create intellectual information systems able to help an investor to make investment decisions.

Classical companies which consult investors and administer their property work employing the teams of specialists of different spheres. Some of them search, collect and group information, others analyse it and draw conclusions. The third forecast future scenarios, the forth summarize and draw final conclusions. It is thought that such work pattern in the century of the internet and other advanced information technologies does not simply correspond not only to the needs and expectations of modern investors but also to the interests of the owners of these companies. Subject to the existence of intense competition among the consulting and property management companies there is a wish to optimize corporate expenses. One of the possible solutions suggests computerizing the part of work executed by specialists, i.e. to create an intellectual information system able to consult investors.

Such a system would be useful both for an investor and a company rendering such kind of services. Firstly, it would let to increase the profitability of consulting and investment management companies. Secondly, it would allow rendering cheaper services to investors and achieve smaller expenses for different investment funds management. Thirdly, computer-assisted system would quicken decision making what is very important at the dynamic market. Investment practice shows that greater return is achieved by those who get, find, correctly evaluate information and come to a decision the first. Plenty of information sources and their formats aggravates and prolongs information perception and its processing time. Thus, modern investment management information system must be able to interpret information, find it, compare and update it. Fourthly, computer-assisted consulting system could ensure greater investor confidentiality and execute preventive market manipulation work. Fifthly, intellectual consulting system would manage to adapt to the changing investor's goals. In such a way a client would always be hedged round with attention and fair offers. At the same time it would be a new leap and standard in client servicing quality as well as new-generation method of investment ideas and investment products sale. Sixthly, it would be possible to transfer the best experience of various specialists into an intellectual consulting system thus avoiding possible human failings. Seventhly, a consulting information system possessing all the above mentioned qualities would increase the number of correct decisions in comparison to classical consulting companies. Eighthly, in case of the success of the implementation of such intellectual investment consultant there is a strong probability to attract more people interested in individual investment or wishing to try it. Moreover, it would allow an investor to know the investment world faster.

Investment decision making, investment portfolio management is a complex and multipronged task. Complexity appears when one looks for

information scattered on the internet or elsewhere, sorts out the methods of securities evaluation and finally draws conclusions. Complexity is that in order to make a decision it is necessary to coordinate the set of coherently and in parallel related processes such as information gathering, carrying out of evaluation, market surveillance etc., and to establish interrelations. Thus, providing of investment recommendation to an investor comes down to the solution of some tasks and to the control and management of separate tasks. It is assumed that it is reasonable to create such a system using software agents or rather to make multi-agent systems of them for task solution.

The object of the scientific research

The object of the scientific research is a multi-agent autonomous expert investment decision support system that forms real-time investment decisions at financial markets and helps to form and manage investment portfolio.

The objective of the work

Work objective is the easement of investment problem solutions for different risk tolerance investors, the facilitation of the process of investment decision making and real time investment decision making applying multi-agent expert investment decision support system.

The tasks of the work

In order to achieve the objective of the work the following tasks are put forward and solved:

1. To investigate and choose the methods of the valuation (assessment) and forecasting methods of financial instruments for multi-agent expert investment decision support system.
2. To investigate and choose or develop the methods of investment portfolio formation and management for multi-agent expert investment decision support system.
3. To identify and choose the suitable software agent's platform to implement multi-agent expert investment decision support system.
4. To create the following methods:
   a) The method of the evaluation of investor risk tolerance, the method of the portfolio property allocation and the method of the providing of investment recommendation for securities;
   b) To create the methodology of an investment decision support system implemented by software agents.
5. On the ground of the experiment outcome to identify and evaluate the opportunities and the main characteristics of multi-agent expert investment decision support system.

Methodology of the research

The objective of the scientific work and the tasks put forward and solved for its achievement include various scientific spheres beginning with social sciences and finishing with exact sciences. So, the work uses a number of research methods. The analysis of literature related to the scientific work theme included the analysis, synthesis and generalization of scientific sources. The analysis of the questions related to the evaluation of securities, consistent pattern of financial markets and portfolio theory models included the methods of logical, comparative and system-oriented analyses. In order to transfer expert knowledge into the system the means and methods of computational intelligence creation were used. For the specification, formation and implementation of a multi-agent investment decision support system generalization, synthesis and concretization methods were used. For the evaluation of system provided results and the possibilities of system itself the methods of mathematical-statistical analysis, simulation modelling, comparative and dimensional analysis were applied.

Scientific and engineering novelty of the work

The prototype of the multi-agent expert investment decision support system presented in the work was implemented offering new scientific and engineering ideas. The system is original and has the following distinctions in comparison to other similar systems:

1. Implemented in the system an original cascading expert fuzzy logic system is designed to evaluate investor risk tolerance.
2. Implemented for the investment portfolio allocation an expert portfolio allocation system does not rest upon previous data about financial markets (securities), what is inevitable using other portfolio allocation methods (for example, Markowitz, Sharpe).
3. The system can observe and provide investment recommendations for a large number of securities from a huge number of financial markets.
4. Investment decision in the system is obtained combining several methods of securities assessment what is absent in other similar systems.
5. The system works autonomously and is able to adapt to the changing investor profile.

Practical significance of work results

The problems raised and solved in the work possessed more practical than scientific character, so bigger part of work results are practical, such as:

1. The developed prototype of multi-agent expert investment decision support system can be used at real financial markets.
2. System usage makes easier the process of investment problems solution.
3. The system works autonomously.

4. The methods and means offered for the implementation of separate system components can be applied in other investment decision support systems.
5. The system allows using more effectively big information sources of financial markets, such as, for example, „Bloomberg“, „Thomson Reuters“ etc.
6. Expert portfolio allocation and securities aspects evaluation systems allow replacing expensive financial market specialists.

Defended propositions

1. Investment decision support system implemented by software agents, as a multi-agent system, when agents transfer investment knowledge by expert systems, allows forming efficient real-time investment decisions at real financial markets.
2. Cascading expert investor risk tolerance evaluation system allows evaluating risk tolerance more sensitively than determinated risk tolerance evaluation methods.
3. Expert portfolio allocation system takes into account the evaluation of investor risk tolerance system and allows allocating portfolio without regard to the number of securities desired to be involved into portfolio and their historical or predicted data.
4. Multi-agent expert investment decision support system can have some implementation specifications (e.g. a mobile one and a communicative one), whereas a particular implementation specification is recommended to choose with relation to the number of securities observed by the system and the profile of users projected by the system.
5. Multi-agent expert investment decision support system can work effectively (in terms of recommendation providing speed) both with small amounts of data and with large volumes of data.

The scope of the scientific work

The doctoral thesis consists of the introduction, four sections, general conclusions, references, the list of author's related publications and appendixes.

The scope of the doctoral thesis is 174 pages without appendixes. The work includes 63 illustrations, 21 tables and 8 appendixes. 243 sources including books, academic papers, theses and Internet sources were used in the course of writing of the scientific work.

1. THEORETICAL AND PRACTICAL ASPECTS OF SECURITIES VALUATION, INVESTMENT DECISION MAKING AND PORTFOLIO FORMATION

In the course of creation and implementation of investment management information systems it is inevitably necessary to analyse and choose proper methods of securities valuation, portfolio formation and management. The first part of the thesis presents a comprehensive analysis of related theories and models taking into consideration that this knowledge will have to be conveyed to software agents.

One of the most important tasks is how to evaluate the "fair" price of securities. There we can use several methods and models.

Fundamental analysis [1] includes the analyses of company financial statements which evaluate plenty of parameters [2] and the analysis of them allows evaluating "fair" security price [3]. The parameters of fundamental analysis chosen and used by MEIDSS for security evaluation are given in Table 1.

Table 1. The parameters of securities evaluation and investment decision making used by MEIDSS

Fundamental analysis indicators	Technical analysis indicators	Expert analysis indicators	Risk analysis indicators
Current liquidity ratio, Cash ratio, Net profitability, EBITDA, ROA, ROE, Debt and capital ratio, Long term debt and equity capital ratio, Capital turnover, Price/Earnings ratio (P/E), Price to sale ratio (P/S), Price to book value (P/Bv), EV/EBITDA, Dividend yield, Dividend payout ratio.	Bollinger bands, Moving average convergence-divergence (MACD), Average directional index (ADX), William %R, On balance volume (OBV), TREND indicator, Indicator reflecting the market value of financial instrument the difference with the value obtained from discounted cash flow method.	Expert evaluation, Upside, Expert evaluation change indicator.	Alpha, Beta, Altman Z-Score, Rating ("Moody's", "Fitch Ratings", "Standard & Poor's Ratings"), Rating outlook.

Source: author's own

Using fundamental analysis as a criterion of securities assessment and investment decision making it is essential to take into account that: a) the method is suitable for long-term company business and financial results forecast, b) the method explains the dynamics of securities price on the ground of fundamental factors, c) the method provides overdue explanation concerning the change of securities price [4].

The substance of technical analysis is the forecast of securities market value taking into account historical data of financial markets [5]. Technical analysis pays considerable attention to the behaviour of market players who use various factors

determining their decision to buy or to sell, whereas the latter can be unrelated to fundamental factors [6]. The indicators of technical analysis are valuated as relations of securities market values and financial markets data and used in order to establish market trends, direction and its strength. Their main objective is to interpret changes in values and give an investor purchase or sale signal. Applying technical analysis it is necessary to take into account that: a) the analysis focuses on what is happening at the markets, explores market dynamics, b) the analysis allows identifying a specific moment of making a transaction (purchase, sale). The indicators of technical analysis chosen and used by MEIDSS are given in Table 1.

Apart from fundamental and technical analyses, used in MEIDSS as the aspects of securities valuation and investment decision making, the work offered and used other forms of analysis called expert and risk analyses. In the course of investment decision making investors use advice of experts what influences their decisions. Risk analysis is intended for securities valuation taking into account the evaluations of ratings companies. The indicators included into these analyses are given in Table 1.

The parameters used in the aspects of securities valuation and investment decision making were chosen with regard to the following criteria: a) the number of indicators should not be large, while large number of indicators would aggravate the implementation and use of expert systems, b) the chosen indicators should fully and objectively reflect the substance of an aspect, c) the data necessary for the calculation (valuation) of chosen indicators should always be accessible to the fullest extent.

The models which can explain the pricing of securities based on efficient-market hypothesis (EMH) were not used in the course of the implementation of a multi-agent system. This was due to some factors: scientific papers of last decade [7, 8, 9] contain more and more doubts corning the efficient-market hypothesis; the EMH models are more oriented towards the hypothesis proving than practically applied for securities assessment; efficient-market theory rests upon a number of assumptions concerning financial market which rarely come true at real financial markets.

Having chosen the aspects of securities valuation and investment decision making it is necessary to discuss the issues of portfolio diversification and allocation. Modern financial markets allow resolving portfolio diversification and portfolio risk management issues, however they also make a lot of other issues necessary to be resolved [10, 11, 12], so MEIDSS was implemented for the best known in science and practice way of portfolio diversification to invest in stocks and bonds [13, 14, 15].

For portfolio allocation we could have used classical Markowitz [16], Sharpe models [17], however their application in MEIDSS would mean the limitation of the number of positions in portfolio. Taking into account this remark we offered and implemented an expert system relating investor risk tolerance

evaluation and portfolio allocation without regard to a number of securities and the history of their financial parameters and thus helping to construct portfolio which would satisfy investor's taken risk.

The decision for investor risk tolerance evaluation is very important for MEIDSS. Improperly evaluated investor risk tolerance will determine false proposals to investor and he will not trust the system and finally will stop using it. Measurement of investor risk tolerance is very complex [18]. We offered the new investor risk tolerance valuation system and it is presented in the third section.

2. THEORETICAL AND PRACTICAL ASPECTS OF SOFTWARE AGENTS

The theory of software agents and multi-agent systems was being developed during the last decade of the XX century, whereas nowadays the researches of the practical application of software agents are predominant. However in summary it can be said that software agents paradigm is still being developed which is confirmed by the fact that one agreement concerning agent definition and agent software implementation standards is still being reached [19, 20].

Software agent is implemented by a program which a little bit differs from other programs in the following substantial moments: its independence level, the flexibility of autonomous behaviour expression. Apart from these substantial differences, in order to correspond to agent definition a program must allow to implement the following qualities: independence, reactivity, communicability, survival, mobility, pro-activity, viability etc. Depending on the level of expression of these qualities in an agent various agents are obtained [21], for example collaborating, interface, mobile, information, reactive, which were used in MEIDSS.

Scientific researches pay particular attention to a mobile agent. Mobile software agent differs from other programs in the following features: it autonomously initiates migrations, the number of migrations is unlimited [21]. In such a way it differs from such programs as various scripts. Mobile agents are important for the enhancement of distributed calculation and distributed control systems.

The analysis of agents, their types and characteristics showed that MEIDSS can be implemented in two abstraction variants (versions), i.e. using communicating or mobile agents. The second section of the thesis comprehensively analyses mobile agent migration process, migration models, migration scenarios as well as agent communication models and scenarios. The analysis allowed evaluating the positive and negative aspects of agent communication and migration. It is a positive that there are some migration and communication models as well as their scenarios. On the downside various communication and migration models and scenarios are developed on different software platforms ignoring general standards which aggravates implementability

and possibilities to research and compare MEIDSS using different migration, communication models and scenarios. The analysis of software agents platforms helped to find a platform called JADE in which the most agent creation standards (becoming global) are implemented according to FIPA organization, and to implement both communicating and mobile multi-agent systems with a help of one tool.

Thanks to possibilities to express in agents the qualities typical for wild life and create more advanced distributed control systems, software agents are used in many spheres. In financial markets agents are applied in two directions: creating simulated models of financial markets (social systems) and creating investment management systems. In the former case the qualities of wild nature expressed in agents are emphasized, whereas these agents can implement more real simulated models of social systems. The latter case dramatizes the importance of aspects which help the agents to improve a distributed control system. Scientific literature contains three systems similar to MEIDSS presented in this work, i.e. Warren [22], MASST [23] and "E-investor" [24]. Unfortunately, it is impossible to compare these four systems directly. Scientific literature contains little information about Warren, MASST systems, i.e. provided information includes the assumptions of system design, preliminary structure and architecture of systems, however the types of agents, their structure, implementation mediums are not worked out in detail, and finally testing results are not provided. "E-investor" system is described on more theoretical level, there is a lack of implementation specification, discussion of testing results. Small volume of information about the creation, implementation and practical tests of such systems can be related to confidentiality criteria applied in financial institutions. On the other hand, even having full information about the systems adequate comparison would be difficult due to different data used in the course of experiments, different sources that were available during experiments, application of different methodologies and tools.

3. FORMATION OF MULTI-AGENTS EXPERT INVESTMENT DECISION SUPPORT SYSTEM

The third section of the thesis presents the phases of MEIDSS analysis, creation and implementation, and emphasizes the moments in which the author offered and implemented new unique decisions adapted in MEIDSS.

Each system is created in reliance on a certain sequence of steps which is defined by an appropriate methodology. The methodologies of multi-agent systems are divided into two groups, i.e. for general purpose and specific. Specific methodologies are general methodologies adapted for the systems completing particular, narrow tasks. Literature analysis did not provide a specific, directly applicable methodology for MEIDSS implementation. So, the author designed a new methodology combining MaSE [25], GAIA [26], JADE [27] methodologies. The substance of novelty lies in the proposal to decompose the system into integral

elements in terms of functions and responsibilities as it can be seen in wild nature or business systems. For example, to replace a technical analysis analyst with one agent possessing appropriate qualities, functional capabilities and responsibilities rather than to construct an analyst from several usual agents, as other methodologies suggest. Such approach determines more complex internal structure of an agent, but later it allows implementing easier and clearer such relations in multi-agent system which correspond to relations between real system elements.

In the course of methodology analysis the main emphasis is laid on the identification of system objectives and preliminary model of how the system works. The objective of MEIDSS is to provide investment recommendations accentuating investor profile and act simulating the business model of investment Management Company. It makes MEIDSS unique with regard to analogical systems such as Warren, MASST and "E-investor". MEIDSS operation principle is explained by the offered and designed horizontal and vertical system structures showed in Figure 1 and Figure 2.

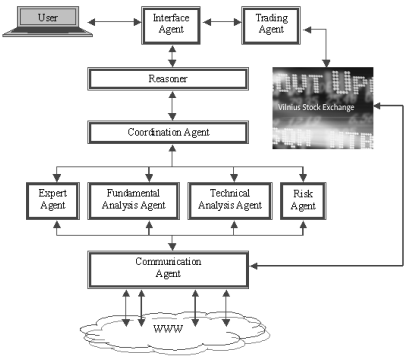

Fig. 1 MEIDSS horizontal structure

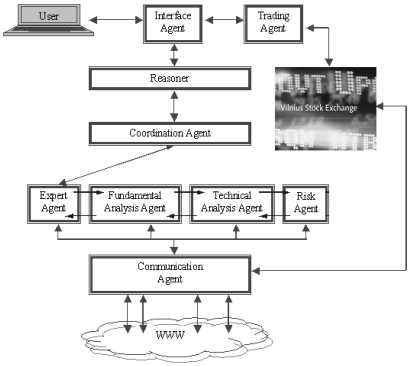

Fig. 2 MEIDSS vertical structure

Horizontal MEIDSS structure in intended to satisfy the needs of conservative investors and corresponds to their decision making principles based on the widest possible securities aspects evaluation round. Vertical MEIDS structure corresponds to speculative investor philosophy when decision is made taking into consideration one securities aspect, and if it generates doubts a decision is grounded taking into account other aspects chosen in successive hierarchical order. MEIDSS implementation by multi-agent system allows proving recommendations with a help of one or the other structure in comparison to other systems which usually use one structure.

In the course of analysis phase agents location question is important. The analysis of agents' location possibilities permitted to notice that MEIDSS can be

implemented by two schemes, i.e. using communication possibilities in one case and mobility possibility in other case. MEIDSS agents' location schemes are showed in Figure 3 and Figure 4.

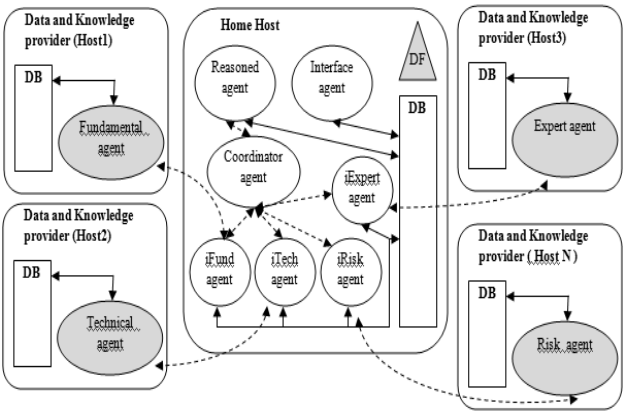

Fig. 3 Agents' location schema when agents communicate

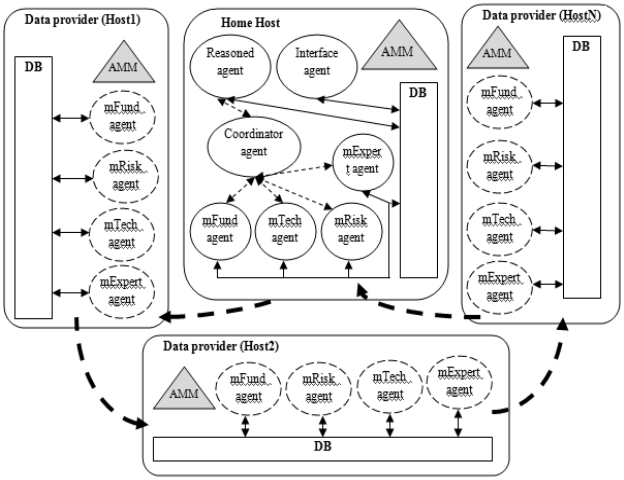

Fig. 4 Agents' location scheme when agents are mobile

In the schemes a thin dashed line with arrows connects intercommunicating agents, a thick dashed line with arrows shows agents' migration way, a solid line with arrows shows data movement, DF – an additional communication agent on JADE platform, AMM – an additional agent administrating agents' migration on JADE platform.

The design phase must provide a particular and satisfactory specification of system components understandable and clear for a programmer who implements the system in the course of implementation phase. It is impossible to specify all the agents in the summary, however it is possible to mention that all agents are intellectual, i.e. expert fuzzy logic systems are implemented in them which allow transferring relevant expert knowledge to agents.

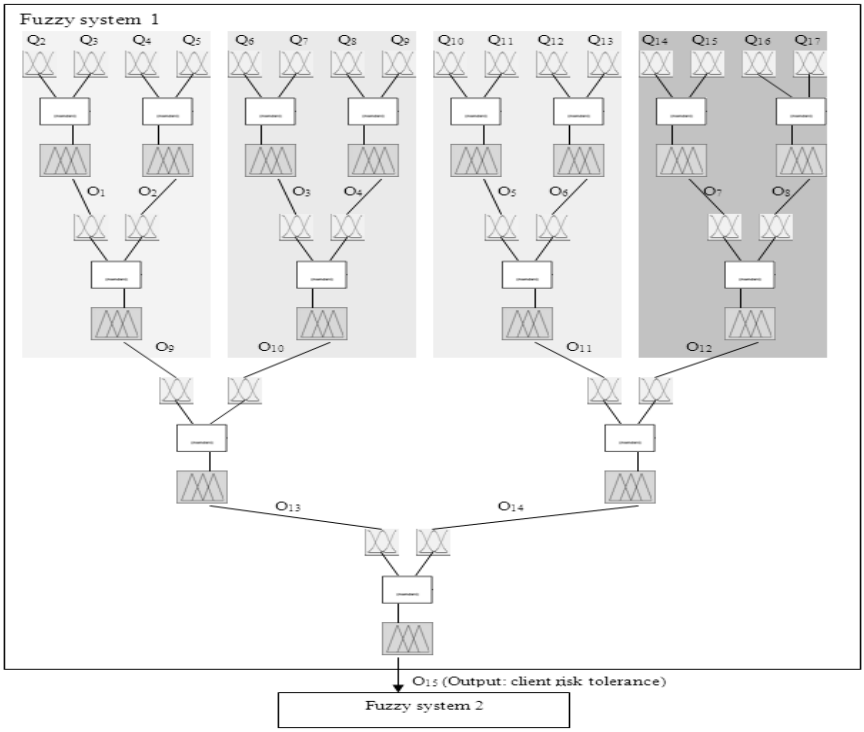

Fig. 5 Cascading structure of risk tolerance evaluation expert system

In the course of creation (design) phase separate attention was given to interface agent, because for the achievement of one of the main objectives of this agent, i.e. investor risk tolerance evaluation, new cascading expert fuzzy logic system which structure is shown in Figure 5. The advantages of risk tolerance evaluation expert systems are following: small number of rules (375 rules), small volume of questionnaire (16 questions-statements) and greater accuracy of decisions.

Creation (design) phase required to find a new portfolio allocation decision suitable for MEIDSS. Portfolio allocation in interpreted a bit differently in

MEIDSS than in Markowitz or Sharpe models. Markowitz and Sharpe models solve square programming task with limitations (restrictions), searching for optimal combination of in a-priori known (chosen for portfolio) security papers weights (amounts) minimizing portfolio variance or other risk measurement or maximizing probable return. This process results in knowing of particular number (amount) of respective security papers which should be bought in portfolio in order to achieve expectable, probable portfolio return or probable riskiness (variance). Such portfolio allocation process is suitable when it is planned or offered to form the portfolio of a small number of securities. If the number of securities intended for investment is large, such portfolio allocation process becomes complex and practically impossible due to difficulty to solve Markowitz and Sharpe equations having a big number of securities. Thus, conceptually such approach to MEIDSS portfolio allocation decision is not suitable because MEIDSS is constructed as a multi-agent system in order to range over and provide recommendations for a large number of securities (from several hundred to thousands). Therefore, the other portfolio allocation way was chosen, as well as other allocation interpretation. MEIDSS allocation is understood as evaluation (establishment) of the proportions to invest into three property classes according to riskiness. On the one hand, such approach does not allow an investor to determine precisely probable portfolio return or risk, but on the other hand it is only a decision support system and the question at issue is if it has to resolve this task? Finally, approach to allocation according to Markowitz, Sharpe is investor's choice from what financial market suggests (provides), while it not always redeems its promise (previous results do not guarantee future results). So, an investor today can choose something and in the course of time he can understand that his choice was wrong and he will be disappointed. Whereas allocation approach implemented in MEIDSS resulting from investor risk tolerance evaluation rather than from historical securities data will let to avoid obviously noticeable difference between investor investment result expectation and reality.

MEIDSS creation (design) phase resulted in creation and implementation of the methods which allow providing recommendation for securities valuating them with a help of several aspects simultaneously. It is not a frequent event in the course of implementation of similar systems, so it can be considered as new knowledge for science and engineering.

4. APPLICATION OF MULTI-AGENTS EXPERT INVESTMENT DECISION SUPPORT SYSTEM AT FINANCIAL MARKETS

MEIDSS was tested at USA financial market and the results obtained from October of 2012 to June of 2013 were summarized. The system is available at the following URL: www.sprendimutechnologijos.lt/webapp. All necessary data MEIDSS takes in real time from "Bloomberg" terminal. The testing was conducted in two states. At the first stage separate parts of MEIDSS were tested,

i.e. expert investor risk tolerance, portfolio allocation, investment decision generation systems. At the second stage MEIDSS was tested.

People who are interested in investment were invited for the evaluation and testing of expert investor risk tolerance system (having published an article-invitation on the website of Traders.Lt: http://www.traders.lt/page.php?id=9177). There were eleven thousands of interested, however only 243 investors tested this system and the data of only 190 investors was suitable for evaluation (taking into account the criterion of questionnaire answer duration) and generalization. The system was evaluated in two aspects. The first one calculates correlation coefficient between investor's self-evaluation and evaluation provided by the system. The correlation coefficient achieved by the system was 0,47, whereas the best achievement found in literature is 0,40 [18]. It is interesting that obtained 0,47 correlation coefficient was achieved "passing" fuzzy evaluations through the cascading system structure. The second aspect evaluates how investors are arranged taking into consideration the errors of risk tolerance system. The results are given in Table 2 at three system specifications.

Table 2. The evaluation of the accuracy of the risk tolerance expert systems of tested investors

Q1=O15±	**Using triangular membership function**	**Using trapezoidal membership function**	**Modified MEIDSS system using ANFIS**
0	15 %	37 %	18 %
1	68 %	56 %	64 %
2	17 %	7 %	0 %
3	0 %	0 %	18 %

Source: author's own

where *Q1* – investor self-evaluation, *O15* – system evaluation. The Table 2 first column value "0" shows part of investors whose risk tolerance was accurately evaluated, "1" – makes a mistake per one tolerance group etc. It can be seen that in all specifications the system making a mistake per one risk tolerance group evaluates per 80% of investors what can be considered as satisfactory achievement.

MEIDSS implemented by inter communicating and mobile agents were compared in the presence of identical conditions. The research showed that mobile MEIDSS evaluates all chosen securities faster than communicating MEIDSS, however in case of greater system distribution time different tends to decrease. All in all, only time criterion should not be the most important. It is advisable to evaluate the uses of which profile dominate as investors, if conservative a mobile MEIDSS is more handy, if speculative – communicating MEIDSS, because it always renews recommendation (without great time pauses as mobile MEIDSS does).

Due to failure to attract permanent real investors, 45 pseudo investors were created for the testing of MEIDSS. They were equally divided into three investor

profile groups (conservative, balances, speculative) and different securities aspect evaluation patterns (15 variants) were chosen. Finance of each pseudo investor (starting amount 100 000 USD) was invested in pursuance of MEIDSS offered property allocation and recommendations. Portfolio allocation was followed not deviating for more than 2% from system recommendation, while in case of deviation the investments in one property class were reduced respectively increasing the investments in other property classes. Investors can include into portfolios different recommended by the system securities from each property groups, while this means that not all recommended securities are included into portfolio, but only their part (investor chooses himself) on the ground of sound logic and with regard to portfolio size. In the course of time the investor follows the recommendations of securities in portfolio and executes operations.

Investment results of pseudo investors obtained within the period under test using MEIDSS are given in Table 3, together with adequate comparative indexes. The first column of the table "Conserv" corresponds conservative investors, "Balanc" – balanced investors, "Speculator" – speculative investors. The second column shows encoded chosen aspects of securities valuation, i.e. "E" – expert analysis aspect, "R" – risk analysis aspect, "T" – technical analysis aspect, "F" – fundamental analysis aspect. Last two columns of Table 3 show the results in such a structure: the first number expressed as a percentage shows investment return within the period under test, in brackets value expressed as a percentage corresponds to the daily standard deviation (variance), the third number is calculated daily Value at risk (VaR) with a 95% level of confidence.

Table 3. Investment results of Pseudo investors in comparison to adequate comparative indexes

Pseudo investor name	**Selected aspects**	**Allocation (%)**	**Achieved investment results with MEIDSS**	**Achieved investment results of an adequate index**
		High risk assets		
Conserv1	E	0.58	1,52% (0.05%) 64,53	0,75% (0,12%) 197,22
Conserv2	R	0.53	0,78% (0.03%) 47,28	0,74% (0,12%) 197,69
Conserv3	F	0.68	1,50% (0.04%) 55,73	0,77% (0,12%) 196,31
Conserv4	T	0.56	2,07% (0.05%) 73,11	0,75% (0,12%) 197,41
Conserv5	ER	0.55	1,65% (0.06%) 86,37	0,75% (0,12%) 197,50
Conserv6	EF	15.43	0,92% (0.20%) 315,44	3,05% (0,11%) 157,06
Conserv7	ET	0.72	0,94% (0.08%) 129,99	0,77% (0,12%) 195,94
Conserv8	RF	0.59	1,25% (0.08%) 118,74	0,75% (0,12%) 197,13
Conserv9	RT	0.53	1,89% (0.03%) 33,75	0,74% (0,12%) 197,68

Pseudo investor name	Selected aspects	Allocation (%)	Achieved investment results with MEIDSS	Achieved investment results of an adequate index
		High risk assets		
Conserv10	FT	0.62	2,41% (0,03%) 37,33	0,76% (0,12%) 196,86
Conserv11	ERF	0.58	0,65% (0,13%) 215,37	0,75% (0,12%) 197,22
Conserv12	ERT	19.28	5,66% (0,22%) 319,76	3,66% (0,13%) 180,46
Conserv13	RFT	0.67	1,26% (0,08%) 114,64	0,76% (0,12%) 196,40
Conserv14	EFT	0.53	1,24% (0,05%) 66,59	0,74% (0,12%) 197,68
Conserv15	ERFT	0.53	2,09% (0,06%) 76,96	0,74% (0,12%) 197,68
Balanc1	E	22.87	5,37% (0,25%) 376,30	4,22% (0,15%) 209,62
Balanc2	R	18.29	4,96% (0,22%) 319,42	3,50% (0,12%) 173,52
Balanc3	F	26.03	6,73% (0,29%) 429,30	4,72% (0,17%) 239,06
Balanc4	T	28.97	8,35% (0,30%) 441,63	5,18% (0,19%) 268,59
Balanc5	ER	18.20	5,84% (0,29%) 442,11	3,49% (0,12%) 172,92
Balanc6	EF	18.49	5,30% (0,18%) 266,40	3,53% (0,12%) 174,88
Balanc7	ET	18.27	5,26% (0,16%) 229,31	3,50% (0,12%) 173,39
Balanc8	RF	22.77	5,77% (0,27%) 402,53	4,20% (0,14%) 208,73
Balanc9	RT	28.90	8,09% (0,30%) 435,61	5,17% (0,18%) 267,87
Balanc10	FT	16.47	5,79% (0,16%) 221,08	3,22% (0,11%) 162,36
Balanc11	ERF	18.37	3,85% (0,21%) 320,11	3,51% (0,12%) 174,06
Balanc12	ERT	17.75	5,62% (0,17%) 239,16	3,42% (0,12%) 169,98
Balanc13	RFT	13.75	3,99% (0,14%) 195,80	2,79% (0,10%) 150,41
Balanc14	EFT	18.15	5,53% (0,22%) 318,17	3,48% (0,12%) 172,59
Balanc15	ERFT	28.26	6,85% (0,35%) 535,81	5,07% (0,18%) 261,31
Speculator1	E	23.38	7,71% (0,34%) 513,36	4,30% (015%) 214,17
Speculator2	R	33.25	8,95% (0,31%) 442,96	5,86% (0,22) 314,05
Speculator3	F	32.64	8,04% (0,30%) 437,94	5,76% (0,21) 307,43
Speculator4	T	24.89	9,91% (0,26%) 365,57	4,54% (0,16%) 228,12
Speculator5	ER	37.33	10,11%(0,35%) 505,57	6,51% (0,25%) 359,23

Pseudo investor name	Selected aspects	Allocation (%)	Achieved investment results with MEIDSS	Achieved investment results of an adequate index
		High risk assets		
Speculator6	EF	37.43	9,13% (0,33%) 486,96	6,52% (0,25%) 360,36
Speculator7	ET	37.43	6,22% (0,62%) 969,07	6,52% (0,25%) 360,36
Speculator8	RF	33.05	9,41% (0,36%) 527,32	5,83% (0,21%) 311,88
Speculator9	RT	30.45	9,63% (0,28%) 392,99	5,42% (0,20%) 284,03
Speculator10	FT	37.63	8,81% (0,35%) 511,32	6,56% (0,25%) 362,61
Speculator11	ERF	26.44	7,69% (0,37%) 551,63	4,78% (0,17%) 243,07
Speculator12	ERT	31.14	4,34% (0,36%) 564,51	5,52% (0,20%) 291,34
Speculator13	RFT	37.53	9,59% (0,36%) 523,47	6,54% (0,25%) 361,48
Speculator14	EFT	37.23	5,52% (0,32%) 483,62	6,49% (0,24%) 358,11
Speculator15	ERFT	35.88	9,80% (0,34%) 496,33	6,28% (0,23%) 343,02

Source: author‘s own

Data of the 3rd table show that in all cases investors profitably controlled their investments with a help of MEIDSS, whereas in the majority of cases (41 of 45 portfolios) they managed to outstrip the returns of adequate comparative indexes. Comparison of pseudo investor risk parameters (standard deviations and VaR) with adequate comparative index shows that investors get higher risk, however logically it corresponds to higher return, so system recommendations are considered to be correct. MEIDSS portfolio management quality was evaluated calculating Sharpe ratios, the analysis of which showed that MEIDSS portfolio management quality is not worse that it corresponds to average investment results at the market.

MEIDSS viability analysis, i.e. how often investors who use MEIDSS make transactions, showed that conservative investors made on the average 8 sale and purchase transactions per 6 months, balanced – 26, and speculative – 29 transactions. Evaluating subjectively these values correspond to real investor experience.

There was conducted a separate research of the profitability of aspects and their combinations used for securities valuation. This research differs from the one summarized in table by the fact that investor success factor is eliminated, i.e. an investor chooses at his own and sole discretion, but not all MEIDSS recommended positions what does not allow to evaluate objectively how good securities valuation aspects operate. The results of this research are given in Table 4.

The data of Table 4 show that if securities are evaluated in all aspects in their combinations more than half of investment decisions are profitable, i.e. the ratio of profitable transactions is higher than of unprofitable ones. When considering in more detail it can be seen that in case of most aspects this ratio ranges from 50 to 75%, i.e. two of three recommended transactions will be profitable. Obtained results show that expert system implemented for securities aspects evaluation answered the purpose. Data of Table 4 allow making one more important generalization, i.e. the use of several matched aspects for the grounding of investment decision allows achieving better investment results in comparison with the use of only one securities valuation aspect.

Table 4. The research of securities valuation aspect profitability

Aspects	Total purchase and sales trades	Amount of profitable trades	Profitable to total trades ratio	Amount of loss trades	Average return on profitable trades	Average return on loss trades	Difference
RF	33	18	55%	15	9.27%	-4.02%	5.25%
ERTF	25	18	72%	7	8.71%	-3.98%	4.73%
R	19	12	63%	7	7.48%	-3.19%	4.29%
ERF	33	20	61%	13	8.79%	-4.70%	4.09%
ER	65	37	57%	28	8.59%	-4.73%	3.86%
EF	61	36	59%	25	8.74%	-5.69%	3.06%
ET	197	144	73%	53	6.59%	-3.82%	2.77%
E	176	113	64%	63	7.76%	-5.16%	2.60%
ERT	46	30	65%	16	7.26%	-4.66%	2.60%
ETF	63	43	68%	20	7.34%	-4.77%	2.57%
RT	37	24	65%	13	6.52%	-4.24%	2.28%
RTF	39	25	64%	14	7.23%	-5.85%	1.39%
TF	48	30	63%	18	5.72%	-4.59%	1.12%
T	750	566	75%	184	3.70%	-3.12%	0.59%
F	28	14	50%	14	7.10%	-7.28%	-0.18%

Source: author's own

GENERAL CONCLUSION

1. Taking into consideration topicality of the work and its purpose in the multi-agent expert investment decision support system for the evaluation

of securities (providing of recommendation) and for portfolio management it is recommended to use securities forecasting methods, i.e. fundamental and technical analyses and made of them hybrid risk and expert analyses.

2. New expert portfolio allocation system (not based upon historical securities data, but rested upon expert evaluation of investor profile) implemented in the multi-agent expert investment decision support system unlike classical Markowitz and Sharpe portfolio allocation methods allow to avoid the restriction of the number of securities in the portfolio. Such portfolio allocation decision allows to consider investors' characteristics especially individually (adaptively), and to form unique portfolios for the investors with identical profiles.
3. New cascading expert investor risk tolerance evaluation system implemented in the multi-agent expert investment decision support system achieves better results than analogous system presented in scientific literature. New system's correlation coefficient between system's investor risk tolerance evaluation and individual investor risk tolerance amounts 0,47 value, whereas this rating of other systems amounts 0,40. Experiments showed that new system evaluates investor risk tolerance 80% correctly (up to one risk level error inclusive).
4. For the implementation of the multi-agent expert investment decision support system JADE platform is recommended. This platform corresponds to the highest international standards (FIPA) for agent systems implementation and allows implementing MAEIDSS in mobile and communicating specifications. It is recommended to choose a specific implementing specification taking into account the number of securities observed by the system and the profile of projected dominating system users. In case of a small number of securities and domination of a conservative investor profile investor a mobile specification is recommended, while in case of a high number of securities and domination of a speculative investor profile a communicating specification is recommended.
5. The results of the research of the multi-agent expert investment decision support system allow stating that the use of coordinated aspects for the grounding of the investment decision allows achieving better investment results than using only one security evaluation aspect.
6. The detailed analysis of the obtained investment results of different investors using multi-agent expert investment decision support system it is possible to state that the system is adaptive and can help different investors to form and manage investment portfolio more qualitatively and profitably, whereas portfolio return is higher or corresponds to the return average obtained at the financial markets. The results of system research allow indicating the main following characteristics of MAEIDSS: the system is

able to work autonomously and in real-time, the system is adaptive, the system is able to provide investment recommendations for high number of securities, the system provides investment recommendations combining several securities evaluation methods and allows choosing their combinations, the system helps to achieve positive investment results, the system can made both high and small numbers of agents.

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2011-2013	Bank "Ukio bankas", Fix income dealer. I take responsibility for bank's fix income portfolio management and bank's customer portfolios management. Also I develop investment strategies for bank and clients using process control and IT technologies (Software agent, Fuzzy logic, Evolutionary computation, Back testing and others).
2002-2011	Investment bank "Finasta", Financial broker. I take responsibility for Kaunas city department customer's transactions in stock exchanges (buying or selling equity and debts securities) and other transactions (Repo, Short sell, etc.). Managing stock accounts. I develop investment strategies for clients.

Certifications: general financial broker's licence, NASDAQ Baltic Stock exchange trader certificate, securities and cash accounts intermediaries of public trading enterprises certificate.

REZIUMĖ

Problemos formulavimas

Sparčiai tebevykstanti informacinės visuomenės ir su ja susijusios aplinkos raida iškelia nemažai iššūkių finansų ir investicijų valdymo srityje. Pasaulio finansų rinkos tapo lengvai pasiekiamos viso pasaulio investuotojams dėka šiuolaikinių informacinių technologijų. Lengvas pasaulio finansų rinkų prieinamumas paskatino investavimu užsiimančių žmonių bendruomenės augimą, o tai savo ruoštu daro svarią įtaką pasaulio ekonomikos raidai. Šiuolaikiniai investuotojai nepasitenkina vien lengvo priėjimo prie finansų rinkų galimybe, jiems reikia informacijos ir žinių. Lengvai pasiekę finansų rinkas investuotojai iš karto susiduria su informacijos apdorojimo ir valdymo problematika, t. y. finansų rinkos yra pasižyminčios ypač sparčiai kintančios informacijos aplinka. Prie tokios informacijos gausos tiek pavieniam investuotojui, tiek instituciniams investuotojams yra keblu spėti aprėpti tokį informacijos kiekį. Susitvarkius su informacijos gausa išlieka nemažiau aktualus uždavinys iš jos išgauti žinias. Finansų rinkos yra vieta, kurioje žinių išgavimas iš finansų rinkose esančios informacijos turi vykti realiu laiku ir greitai. Laikas yra svarbus investavimo sėkmei.

Iškeltos problemos turi praktinio pobūdžio charakterį, o jų sprendimui reikia apjungti įvairių sričių mokslo žinias, kaip ekonomikos, finansų valdymo, matematikos, informacinių technologijų ir kitas teorijas. Apibendrinant galima pasakyti, kad šiuolaikiniams investuotojams reikalingas kompleksinis sprendimas (apjungiantis informacijos ir žinių valdymą) palengvinantis susiorientavimą finansų rinkose, kuris galėtų būti realizuotas modernia investicijų valdymo ar investicinių sprendimų paramos informacine sistema. Tokiu būdu darbo problematika susiveda į investicinių sprendimų informacinės sistemos kūrimo problematiką.

Darbo aktualumas

Šiandien norint sėkmingai investuoti, prekiauti ir spekuliuoti finansų rinkose nepakanka vien gerai išmanyti fundamentalią, techninę ar kitą vertybinių popierių vertinimo ir portfelio valdymo metodikas. Prekybai finansinėmis priemonėmis persikėlus į internetinę erdvę investuotojams iškilo nauji iššūkiai.

Pirmiausia finansų rinkos tapo globalios, t. y. iš vienos pusės investuotojams investuoti, bet kuriame pasaulio regione tapo labai paprasta, o iš kitos pusės atsiranda poreikis išmanyti atitinkamo regiono specifiką ir prie jos prisitaikyti bei išmokti joje dirbti. Antra, finansų rinkos tapo dinamiškos, t. y. jos greitai gali keisti kryptis, todėl iškyla poreikis nepertraukiamai sekti informaciją, ją analizuoti ir nedelsiant daryti išvadas bei jomis remiantis priimti investicinius sprendimus. Vadinasi, investicijų valdymas yra pakankamai komplikuotas ir kompleksiškas uždavinys. Natūraliai atsiranda poreikis kurti intelektualias

informacines sistemas galinčias padėti investuotojui priimti investicinius sprendimus.

Klasikinės investuotojus konsultuojančios ar jų turtą valdančios bendrovės veikia samdydamos įvairių sričių specialistų komandas. Vieni iš jų ieško, renka, grupuoja informaciją, kiti ją analizuoja ir daro išvadas. Treti prognozuoja būsimus scenarijus, ketvirti apibendrina ir priima galutinius sprendimus. Manoma, kad toks veiklos modelis amžiuje, kuriame dominuoja internetas ir kitos pažangios informacinės technologijos, paprasčiausiai nebeatitinka šių dienų investuotojų poreikių ir lūkesčių, o ir tokių bendrovių savininkų interesų. Esant aršiai konkurencijai konsultuojančių ir turtą valdančių bendrovių tarpe, iškyla noras optimizuoti bendrovės veiklos kaštus. Viename iš galimų sprendimų siūloma dalį specialistų atliekamų funkcijų automatizuoti, t. y. kurti intelektualią investuotojus konsultuojančią informacinę sistemą.

Tokia sistema būtų naudinga investuotojui ir šias paslaugas teikiančiai bendrovei. Pirmiausia tai leistų padidinti pačių konsultacinių ir valdymo įmonių pelningumą. Antra, tai leistų pigiau teikti paslaugas investuotojams ir pasiekti mažesnius įvairių investicinių fondų valdymo kaštus. Trečia, automatizuota sistema pagreitintų sprendimo priėmimą, kas dinamiškoje rinkoje labai svarbu. Iš investavimo praktikos žinoma, kad didesnę grąžą pasiekia tie, kurie pirmieji gauna, suranda ir teisingai įvertina informaciją bei pirmieji padaro sprendimus. Informacijos šaltinių ir jų formatų gausa apsunkina ir prailgina informacijos suvokimo, jos apdorojimo laiką, todėl šiuolaikinė investicijų valdymo informacinė sistema turėtų mokėti interpretuoti informaciją, ją surasti, palyginti ir atnaujinti. Ketvirta, automatizuota konsultavimo sistema galėtų užtikrintų didesnį investuotojo konfidencialumą ir atlikti prevencinį manipuliavimo rinka darbą. Penkta, intelektuali konsultavimo sistema sugebėtų prisitaikyti prie kintančių investuotojo tikslų. Tokiu būdu klientas visada būtų apsuptas dėmesio ir jam tinkamais pasiūlymais. Kartu tai būtų naujas klientų aptarnavimo kokybės šuolis ir standartas bei naujos kartos investicinių idėjų, investicinių produktų pardavimo metodas. Šešta, į intelektualią konsultavimo sistemą būtų galima perkelti geriausią įvairių sričių specialistų patirtį, tokiu būdu išvengiant galimų žmogiškųjų klaidų. Septinta, visomis išvardintomis savybėmis pasižyminti konsultavimo informacinė sistema tikėtina padidintų teisingų sprendimų skaičių lyginant su klasikinėmis konsultavimo įmonėmis. Aštunta, pavykus realizuoti tokį intelektualų investicijų konsultantą tikėtina, kad būtų pritrauktas didesnis žmonių kiekis besidomintis savarankišku investavimu ar norinčiu tai išbandyti. Kartu tai leistų investuotojui greičiau pažinti investicijų pasaulį.

Investicinių sprendimų priėmimas, investicinių portfelių valdymas yra komplikuotas ir kompleksiškas uždavinys. Komplikuotumas atsiranda internete ar kitur ieškant išbarstytos informacijos, atsirenkant finansinių priemonių vertinimo metodus, galiausiai darant išvadas. Kompleksiškumas pasireiškia tuo, kad padaryti sprendimą reikia tarpusavyje suderinti eilę nuosekliai ir lygiagrečiai susijusių

procesų nuo informacijos surinkimo, vertinimo atlikimo, rinkos stebėjimo ir t. t., bei nustatyti tarpusavio sąryšius. Vadinasi, investavimo rekomendacijos investuotojui pateikimas susiveda į kelių uždavinių sprendimą ir atskirų uždavinių kontrolę bei valdymą. Manoma, kad tokią sistemą kurti tikslinga naudojant programinius agentus, o tiksliau iš jų sudaryti daugiaagentines sistemas uždaviniui spręsti.

Tyrimų objektas

Darbo tyrimų objektas – daugiaagentinė ekspertinė investicinių sprendimų paramos sistema, formuojanti realiu laiku investavimo sprendimus finansų rinkose ir padedanti formuoti bei valdyti investicijų portfelį.

Darbo tikslas

Darbo tikslas – skirtingos rizikos toleravimo investuotojams investavimo problemų sprendimų, investicinių sprendimų priėmimo proceso ir realaus laiko investicinių sprendimų priėmimo proceso palengvinimas pritaikant daugiaagentinę ekspertinę investicinių sprendimų paramos sistemą.

Darbo uždaviniai

Darbo tikslui pasiekti iškelti ir sprendžiami šie uždaviniai:

1. Įvertinti ir parinkti finansinių priemonių vertės nustatymo (įvertinimo) ir prognozavimo metodus daugiaagentinei ekspertinei investicinių sprendimų paramos sistemai.
2. Parinkti ir (arba) sudaryti investicijų portfelio sudarymo ir valdymo metodus.
3. Nustatyti ir parinkti realizuoti daugiaagentinei ekspertinei investicinių sprendimų paramos sistemai tinkamą programinių agentų platformą.
4. Sukurti metodus:
   b) Investuotojo tolerancijos rizikai įvertinimo, turto alokacijos portfelyje ir investicinės rekomendacijos finansinei priemonei suteikimo metodus;
   c) Sukurti investicinių sprendimų paramos sistemos realizuojamos programiniais agentais metodą.
5. Sukurti ir ištestuoti sistemą bei įvertinti pasiektus rezultatus. Remiantis sistemos testavimo rezultatais nustatyti ir įvertinti sistemos galimybes bei pagrindines sistemos charakteristikas.

Tyrimų metodika

Disertacijos tikslas ir jo pasiekimui iškelti, ir sprendžiami darbo uždaviniai apima įvairias mokslo sritis nuo socialinių iki tiksliųjų mokslų, todėl darbe buvo pritaikyta eilė tyrimų metodikų. Su disertacijos tema susijusios literatūros analizei buvo taikoma mokslinių šaltinių analizė, sintezė ir apibendrinimas. Klausimams susijusiems su finansinių priemonių įvertinimo (įkainojimo), su finansų rinkų

dėsningumų ir su portfelio teorijos modeliais analizuoti buvo taikyti loginės, lyginamosios ir sisteminės analizės metodai. Ekspertinių žinių perkėlimui į sistemą buvo naudoti skaitinio intelekto kūrimo priemonės ir metodai. Daugiaagentinės investicinių sprendimų paramos sistemos detalizavimui, sudarymui ir realizavimui taikyti apibendrinimo, sintezės, konkretizavimo metodai. Sistemos teikiamų rezultatų ir pačios sistemos galimybių įvertinimui buvo panaudoti matematinės-statistinės analizės, imitacinio modeliavimo, palyginimo ir erdvinės analizės metodai.

Darbo mokslinis ir inžinerinis naujumas

Darbe pristatomas daugiaagentinės ekspertinės investicinių sprendimų paramos sistemos prototipas buvo realizuotas pasiūlius naujas mokslines bei inžinerines idėjas. Sistema yra originali ir prieš panašias sistemas išsiskiria šiais sprendimais:

1. Sistemoje realizuota originali kaskadinės (pakopinės) struktūros ekspertinė neraiškių aibių logikos sistema skirta investuotojo tolerancijos rizikai įvertinimui.
2. Investicijų portfelio alokavimui realizuota ekspertinė portfelio alokavimo sistema, kuri nesiremia praeities duomenimis apie finansų rinkas (finansines priemones), kas yra neišvengiama kituose portfelio alokavimo metoduose (pvz. Markowitz, Sharpe).
3. Sistema gali stebėti ir teikti investicines rekomendacijas dideliam skaičiui finansinių priemonių iš didelio skaičiaus finansų rinkų.
4. Investicinis sprendimas sistemoje gaunamas lygiagrečiai apjungiant kelis finansinių priemonių įvertinimo metodus, ko nėra panašiose sistemose.
5. Sistema dirba autonomiškai ir geba adaptuotis prie kintančio investuotojo profilio.

Darbo rezultatų praktinė reikšmė

Darbe iškeltos ir spręstos problemos turėjo labiau praktinio pobūdžio charakterį, nei mokslinį, todėl didžioji dalis darbo rezultatų yra praktiški, kaip:

1. Sukurtą daugiaagentinės ekspertinės investicinių sprendimų paramos sistemos prototipą galima naudoti realiose finansų rinkose.
2. Sistemos naudojimas palengvina investicinių sprendimų priėmimo procesą.
3. Sistema veikia autonomiškai.
4. Atskirų sistemos komponentų realizavimui pasiūlyti metodai ir priemonės gali būti pritaikomi, ir kitose investicinių sprendimų paramos sistemose.
5. Sistema leidžia efektyviau išnaudoti didelius finansų rinkų informacinius šaltinius, kaip pvz. „Bloomberg“, „Thomson Reuters“ ir kitus.

6. Ekspertinės portfelio alokavimo ir finansinių priemonių aspektų įvertinimo sistemos leidžia pakeisti brangiai apmokamus finansų rinkų specialistus.

Ginamieji teiginiai

1. Investicinių sprendimų paramos sistema realizuota programiniais agentais, kaip daugiaagentinė sistema, o agentams investavimo žinias perteikiant ekspertinėmis sistemomis, leidžia formuoti realiu laiku ir realiose finansų rinkose efektyvius investicinius sprendimus.
2. Kaskadinė (pakopinė) ekspertinė investuotojo tolerancijos rizikai įvertinimo sistema leidžia jautriau įvertinti toleranciją rizikai, nei determinuoti tolerancijos rizikai įvertinimo metodai.
3. Ekspertinė portfelio alokavimo sistema atsižvelgia į investuotojo tolerancijos rizikai sistemos įvertinimą ir leidžia alokuoti portfelį neprisirišant prie pageidaujamų įtraukti į portfelį finansinių priemonių skaičiaus ir prie jų istorinių ar prognozuojamų duomenų.
4. Daugiaagentinė ekspertinė investicinių sprendimų paramos sistema gali turėti kelias realizavimo specifikacijas (pvz. mobilią ar komunikuojančią), o konkrečią realizavimo specifikaciją rekomenduotina pasirinkti atsižvelgiant į sistemos stebimų finansinių priemonių skaičių ir prognozuojamų sistemos vartotojų profilį.
5. Daugiaagentinė ekspertinė investicinių sprendimų paramos sistema gali efektyviai (rekomendacijų teikimo greičio prasme) dirbti tiek su mažos apimties duomenimis, tiek su didelės apimties duomenimis.

Darbo rezultatų aprobavimas

Disertacijos tema yra paskelbti 8 moksliniai straipsniai, penki iš kurių publikuoti leidiniuose įtrauktuose į *Thomson Reuters Proceedings* duomenų bazę, 2 – Lietuvos Mokslo Tarybos patvirtinto sąrašo tarptautinėse duomenų bazėse referuojamame leidinyje, 1 – kituose recenzuojamuose mokslo leidiniuose. Pristatyti 5 pranešimai tarptautinėse mokslinėse konferencijose.

2014 m. straipsnis pavadinimu „Development and investigation of multi-agent expert investment decision support system“ publikavimui pateiktas į žurnalą *Transformations in Business & Economics* (žurnalas įtrauktas į *Thomson Reuters* duomenų bazę, ISSN 1648-4460). Straipsnio būsena – priimtas spaudai.

Bendrosios išvados

1. Atsižvelgiant į darbe nagrinėjamą problematiką ir darbo tikslą, daugiaagentinėje ekspertinėje investicinių sprendimų paramos sistemoje finansinių priemonių įvertinimui (rekomendacijos suteikimui) ir bendrai portfelio valdymui rekomenduotina taikyti finansinių priemonių

prognozavimo metodus, t. y. fundamentalią ir technines analizes bei iš jų sudarytas hibridines rizikos ir ekspertines analizes.

2. Daugiaagentinėje ekspertinėje investicinių sprendimų paramos sistemoje įdiegta nauja ekspertinė portfelio alokavimo sistema (nesiremianti istoriniais finansinių priemonių duomenimis, o pagrįsta ekspertiniu investuotojo profilio įvertinimu) skirtingai, nei klasikiniai Markowitz ir Sharpe portfelio alokavimo metodai, leidžia išvengti finansinių priemonių skaičiaus ribojimo portfelyje. Toks portfelio alokavimo sprendimas leidžia ypač individualiai (adaptyviau) atsižvelgti į investuotojo charakteristikas, o identiškų profilių investuotojams susidaryti unikalius portfelius.
3. Daugiaagentinėje ekspertinėje investicinių sprendimų paramos sistemoje įdiegta nauja kaskadinės struktūros ekspertinė investuotojo tolerancijos rizikai įvertinimo sistemą pasiekia geresnius rezultatus, nei mokslinėje literatūroje pateikiamos analogiško tikslo sistemos. Naujos sistemos pasiekiamas koreliacijos koeficientas tarp sistemos investuotojo tolerancijos rizikai įvertinimo ir investuotojo savarankiško įsivertinimo tolerancijos rizikai siekia 0,47 reikšmę, kai kitų sistemų šis įvertis siekia 0,40 reikšmę. Eksperimentai parodė, kad naujoji sistema 80% investuotojų teisingai (imtinai iki vienos rizikos lygio suklydimo) įvertina toleranciją rizikai.
4. Daugiaagentinei ekspertinei investicinių sprendimų paramos sistemai realizuoti rekomenduotina JADE platforma. Platforma atitinka aukščiausius tarptautinius standartus (FIPA) agentinėms sistemoms realizuoti bei leidžia DEISPS realizuoti mobilia ir komunikuojančia specifikacijomis. Konkrečią specifikaciją rekomenduotina pasirinkti atsižvelgiant į sistemos stebimų finansinių priemonių skaičių ir prognozuojamų dominuosiančių sistemos vartotojų profilį. Esant mažam stebimų finansinių priemonių skaičiui ir dominuojant konservatyviam investuotojų profiliui rekomenduotina mobili specifikacija, o esant dideliam stebimų finansinių priemonių skaičiui ir dominuojant spekuliatyviam investuotojų profiliui rekomenduotina komunikuojanti specifikacija.
5. Daugiaagentinės ekspertinės investicinių sprendimų paramos sistemos tyrimo rezultatai leidžia teigti, kad investiciniam sprendimui pagrįsti apjungus finansinių priemonių įvertinimo aspektus, pasiekiami geresni investiciniai rezultatai, nei naudojantis tik vienu finansinės priemonės įvertinimo aspektu.
6. Detaliai išanalizavus įvairių profilių investuotojų pasiektus investicinius rezultatus naudojantis DEISPS, galima teigti, kad sistema yra adaptyvi ir gali kokybiškai bei pelningai įvairaus profilio investuotojui padėti sudaryti ir valdyti investicijų portfelį, kurio grąža yra aukštesnė arba atitinka finansų rinkose pasiekiamus grąžos vidurkius. Sistemos tyrimo rezultatai leidžia pažymėti šias pagrindines DEISPS charakteristikas: sistema geba dirbti

autonomiškai ir realiu laiko režimu, sistema adaptyvi, sistema geba teikti investicines rekomendacijas dideliam skaičiui finansinių priemonių, sistema investicijų rekomendacijas teikia apjungdama kelis finansinių priemonių įvertinimo metodus ir leidžia pasirinkti jų derinius, sistemos pagalba pasiekiami teigiami investavimo rezultatai, sistemą gali sudaryti tiek didelis, tiek mažas agentų skaičius.

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