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Risk avoiding strategy in multi-agent trading system

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Abstract—**The authors of this paper present an approach to trading strategy design for a multi-agent system which supports investment decisions on the stock market. The individual components of the system, the functionalities, and the mechanism of assessing the individual agents are briefly described. The main component, the supervisor agent, uses as a strategy a consensus method to reduce the level of investment risk. This method allows the coordination of the work of agents, and on the basis of decisions provided by the agents, and presents trading advice to the investor. The strategy testing has been done on FOREX quotes, namely on the pair EUR/USD. The results of the research are described and the directions of the further development of the platform are provided in the conclusion.**

I. Introduction

GENERALLY, the algorithms used in stock trading decision support systems can be based on mathematics, statistics, economics, or artificial intelligence [1;2;3;4;5;8]. Investing in financial instruments is always related to the occurrence of risk as the uncertainty of the future performance of investments. This uncertainty occurs due to links between the functioning of the capital market and factors such as the economic policy of the Government, the level of interest rates, exchange rates, or phases of the business cycle

A very important element of risk management is to measure these risks, to estimate the level of risk that is being taken in relation to the size of the capital which is at the disposal of the investor, as well as the investment limits. In general, the risk measures can be divided into three basic categories [8] :

- volatility measures (i.e. average deviation, average coefficient of variation),
- sensitivity measures (i.e. beta coefficient, delta coefficient),
- downside measures (i.e. Value at Risk).

In order to reduce the risk, diversification is applied. That is, investing in different types of instruments as well as various instruments of the same type. The diversity of investment reduces the risk of the instrument with the greatest level of risk, however, but on other site also lowers the expected investment rate of return . Another technique to reduce the level of risk is to take investment decisions with the use of multiple methods at the same time.

The aim of this paper is to present the trading strategy in a multi-agent system which avoids risky investment decisions due to the integration and cooperation of the agents. In the design of our system, called A-Trader, the accuracy of predictions, the orientation on online trading, the improvement of the financial knowledge base, and the ability to adapt to the changing market environment were all important requirements.

The paper is divided into three main sections. The first one presents the functional architecture of the system. The individual components of the system and the manner of communication between them are discussed. In the second, the consensus strategy used by the Supervisor agent to reduce the level of investment risk is described. The last part is a description of the results of the Supervisor strategy testing and performance analysis on the FOREX quotes. In conclusion, the further development direction of the A-Trader system are also described.

II. Multi-agent system – architecture and functions

The key ideas of A-Trader have been already detailed in our previous papers [9;10]. As a brief reminder: the A-Trader architecture in fig.1 sketches the main agents and components, namely: Notification Agent (NA), Historical Data Agent (HDA), Cloud of Computing Agents (CCA), Market Communication Agent (MCA), User Communication Agent (UCA), Database System (DS), Supervisor (S).

Let us describe briefly each agent of the system. The Notification Agent (NA) ensures efficient communication within the system. The Notification Agent forwards the information on the status change of a given agent to all agents that are recorded in the Notification register as the clients/observers of its signals. The notification is performed by triggering an appropriate Web method (SOAP) in all the agents from the list of listeners to the indicated signal. Next, it records the information on the status change of the

Notification Agent in the database. This capability of the Notification Agent makes the system flexible and scalable, provides the possibility to add and remove agents easily, and ensures the independence of the system from the physical position of the agent. Notification Agent sends the Base Agents and Intelligent Agents signals (decisions) to the Supervisor Agent. On the basis of these decisions, the Supervisor strategies are realized.

Another system agent downloads financial data from the Database System (SD) and delivers them to the agents according to their needs. This is the role of the Historical Data Agent (HDA).

The next system component is the Cloud of Computing Agents (CCA), consisting of Basic Agents Cloud (BAC), Intelligent Agents Cloud (IAC), and User Agents Cloud (UAC).

The Basic Agents Cloud (BAC) is a group of agents which pre-process data and compute the basic technical analysis indicators. The agents which possess their own knowledge base, which can learn and change their parameters and their internal state, create another component of the agents cloud, called the Intelligent Agents Cloud (IAC). This group of agents includes all the solutions based on artificial intelligence (genetic algorithms, neural networks, expert systems, etc.), agents analyzing text messages, agents observing user behaviour. The result of the operation of Basic Agents and the Intelligent Agents are the decisions which are transferred to the Supervisor Agent.

The User Agents Cloud (UAC), in turn, is the cloud containing the agents created by external users. Separating this part of the system provides the possibility of integrating the User Agents with the system without the necessity of installing the agent on the servers.

The communication of the system with the external environment is ensured by the Market Communication Agents (MCA). On the one hand, these agents supply the news from financial markets and quotations of the available securities. On the other hand, they are responsible for performing open and close position orders.

Fast and easy visualisation of the results of the agents is an important aspect in verifying the correctness of its operation. Such visualisation is possible in the system due to the User Communication Agents (UCA). The Communication Agent allows the user to communicate its own recommendations to the Intelligent Agents. It enables the change of the parameters of a selected agent or the suggestion for the Supervisor on which mechanisms are supposed to influence investment decisions, and to what extent.

The key component of the system is the Supervisor (S). The main goal of this agent is to generate profitable trading advice that reduces the investment risk. The supervisor, by using different strategies, coordinates the computing on the basis of decisions generated by Basic and Intelligent agents, and provides the final decision to the trader. Fig. 2 presents the general functional schema of A-Trader. A few strategies were developed in the system such as the consensus strategy, the rule-based strategy, and the evolution-based strategy.

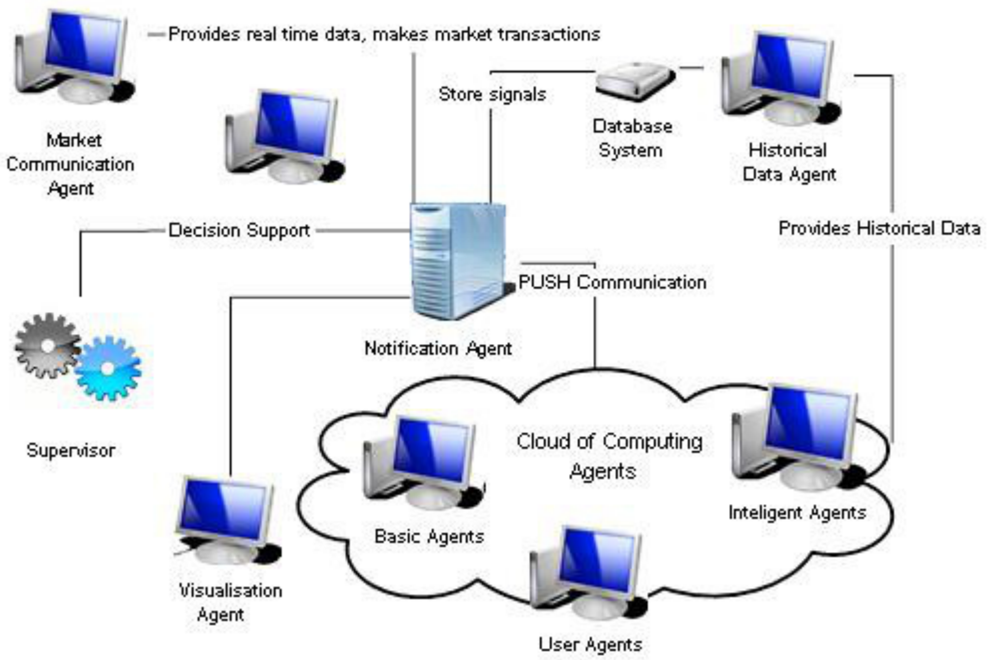

Fig.1 A-Trader system architecture
Source: Own work.

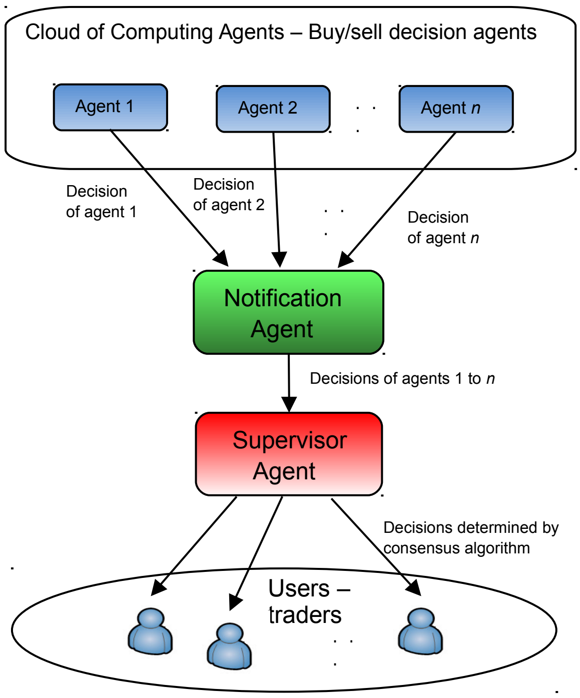

Fig.2 Functional schema of A-Trader
Source: Own work.

The strategies operate on the following assumptions:

1. Cloud of computing agents – Buy/sell decision agents, the intelligent programs, which, on the basis of the signals received from the Notification Agent, take the specified decision on buy/sale. Each agent has been implemented with a different method of computation and decision making. Buy/sell decision agents send the decisions to Notification Agent.
2. The Supervisor Agent – functions on the basis of the strategies that allow the determination of the final decisions on the basis of separate decisions generated by individual agents (read from Notification Agent), which are to be presented to the users (Traders). As a consequence, it is possible to reduce the level of risk associated with investing in a financial instrument.
3. Users – mostly traders who invest on financial markets, or bots (automatic traders).

The multi-agent system is composed of the agents being capable of generating independent decisions. These may be mutually consistent or completely contradictory decisions. Such mutually exclusive decisions are e.g. the open and close positions generated by two independent agents at the same time. The conflicts are resolved by the Supervisor, which observes the decisions of all the Cloud of Computing Agents and the Intelligent Agents, and assesses their effectiveness in investing and risk. The Supervisor determines which agents are taken into consideration when making an investment decision and whose advice is ignored based on the collected information.

The Supervisor may apply various strategies to generate the final trading decision. In the paper, the consensus method is detailed and tested. The relevant literature [13] defines consensus as an agreement and originates from choice theory. Consensus is based on the existing solutions to a given problem, is very close to them, but does not have to be one of these solutions. Hence, the financial decision presented to the user is a decision formed on the basis of the generated trading decisions [11].

The consensus is elaborated in three major stages. In the first stage it is necessary to carefully examine the structure of the set of financial decisions. In the second stage it is necessary to define the distance functions among particular decisions. The third stage is an elaboration of consensus algorithms that generate a decision, that the distance between this decision (consensus), and the individual decisions is minimal (according different criteria) [12].

The specificity of the problem being solved (a large set of open and close position signals) due to the dynamically changing market environment, the implementation requires an extremely high performance of the system. Therefore, from a software point of view, to make the implementation easier, each agent is activated within its container, which isolates it from the environment and which encapsulates the communication with the Notification Agent. Note that multiple containers may be activated on one machine.

The objective of the isolated agents and their transfer to the cloud is to ensure asynchronous cooperation and to enable the performance of specialised operations on the dedicated environment. For example, computing algorithms may be performed synchronously on the computers equipped with multi-processor NVIDIA graphic cards.

III.`Supervisor - Consensus Strategy

The consensus method was implemented as one of the main strategies of the Supervisor. The consensus algorithm runs automatically after providing the decision advices by individual agents.

Each financial decision must be represented by using a concrete structure (the first stage of consensus determining). Such structure was defined in work [6]. In our system, the financial decision consists in a trading position relating to a given quote, such as EUR/USD, USD/GBP, etc. The formal definition of this structure is the following:

Definition 1.

Decision P about finite set of financial instruments $E=\{e_1, e_2, \ldots, e_N\}$ is defined as a set:

$$P=\langle \{EW^+\}, \{EW^\pm\}, \{EW^-\}, Z, SP, DT \rangle \quad (1)$$

where:

1) $EW^\pm=\langle e_o, pe_o\rangle, \langle e_q, pe_q\rangle, \ldots, \langle e_p, pe_p\rangle$

Couple $\langle e_x, pe_x \rangle$, where: $e_x \in E$ and $pe_x \in [0,1]$ denote a financial instrument and this instrument's participation in set EW^{+}.

Financial instrument $e_x \in EW^{+}$ is denoted by e_x^{+}.

The set EW^{+} is called a positive set; in other words, it is a set of financial instruments about which the agent knows the decisions to buy, and the volume of this buying.

2) $EW^{\pm} = \langle e_r, pe_r \rangle, \langle e_s, pe_s \rangle, \dots, \langle e_t, pe_t \rangle$.

Couple $\langle e_x, pe_x \rangle$, where: $e_x \in E$ and $pe_x \in [0,1]$ denote a financial instrument and this instrument's participation in set $EW^{\pm}$.

Financial instrument $e_x \in EW^{\pm}$ will be denoted by $e_x^{\pm}$.

The set $EW^{\pm}$ is called a neutral set, in other words, it is a set of financial instruments, about which the agent does not know that buy or sell. If these instruments are held by an investor, that they should not be sold, or if they are not in possession of the investor, should not be bought by them.

3) $EW^{-} = \langle e_u, pe_u \rangle, \langle e_v, pe_v \rangle, \dots, \langle e_w, pe_w \rangle$.

Couple $\langle e_x, pe_x \rangle$, where: $e_x \in E$ and $pe_x \in [0,1]$, denote financial instrument and this instrument's participation in set EW^{-}.

Financial instrument $e_x \in EW^{-}$ will be denoted by e_x^{-}.

The set EW^{-} is called a negative set; in other words it is a set of financial instruments of which the agent knows that these elements should sell.

4) $Z \in [0,1]$ - predicted rate of return.

5) $SP \in [0,1]$ - degree of certainty of rate Z. It can be calculated on the basis of the level of risk related with the decision.

6) DT - date of decision.

A situation in which the structures of a decision in the system differ, or the values of their attributes are different, is called a knowledge conflict of these agents. This conflict results in the taking by agents of various, often contradictory decisions concerning buying and selling a financial instrument.

Consensus is determined on the basis of a decision generated by different agents working in a system. We call a set of such decisions a profile and define it as follows [7]:

Definition 2.

E set of financial instruments $E = \{e_1, e_2, \dots, e_N\}$ is given. In the case of A-Trader it is a set of pairs of currencies, e.g. EUR/USD, USD/GBP.

A profile A = $\{A^{(1)}, A^{(2)}, \dots, A^{(M)}\}$ is called a set of M decisions of finite set of financial instrument E, such that:

$$A^{(1)} = \langle \{EW^{+}\}^{(1)}, \{EW^{\pm}\}^{(1)}, \{EW^{-}\}^{(1)}, Z^{(1)}, SP^{(1)}, DT^{(1)} \rangle$$

$$A^{(2)} = \langle \{EW^{+}\}^{(2)}, \{EW^{\pm}\}^{(2)}, \{EW^{-}\}^{(2)}, Z^{(2)}, SP^{(2)}, DT^{(2)} \rangle$$

....

$$A^{(M)} = \langle \{EW^{+}\}^{(M)}, \{EW^{\pm}\}^{(M)}, \{EW^{-}\}^{(M)}, Z^{(M)}, SP^{(M)}, DT^{(M)} \rangle \quad (2)$$

In the case of A-Trader the profile is a set of decisions generated by Base Agents and Intelligent Agents. On the basis of these decisions, the Supervisor strategy is executed.

At the A-Trader system, the values Z, SP are provided by Base Agents and Intelligent Agents (e.g. by using statistical forecasting methods, or artificial intelligence methods) or by Supervisor (e.g. on the basis of agent performance evaluation). The values DT are generated, by all agents, together with the signals (decisions).

The Supervisor strategy is carried out according to the following consensus algorithm:

Algorithm 1.

Data: The profile A= $\{A^{(1)}, A^{(2)}, \dots, A^{(M)}\}$consists of M agents' decisions.

Result: Consensus

$CON = \langle CON_{+}, CON_{\pm}, CON_{-}, CON_{Z}, CON_{SP}, CON_{DT} \rangle$

according to A. The consensus is a decision generated by the Supervisor Agent. This decision consists of the same attributes as the decision of the agents (e.g. CON_+ mean consensus of the EW^+ set), but the values of these attributes differ.

Begin

```
1:  CON+ = CON± = CON- = ∅, CONZ = CONSP = CONDT = 0
2:  j:=1.
3:  i:=+.
4:  If ti(j) > M/2 then CONi:= CONi ∪{ej}
    Go to:6.
5:  If i=+ then i:=±
    If i=± then i:=-
    If i=-, then Go to:6
    Go to:4.
6:  If j<N then j:=j+1 Go to:3
    If j≥N then Go to:7.
7:  i:=Z.
8:  Determine pr(i).
9:  k_i^1 = (M + 1) / 2 , k_i^2 =(M + 2) / 2 .
10: k_i^1 ≤ CON_i ≤ k_i^2 .
11: If i=Z then i:=SP
    If i:=SP then i:=DT
    If i:=DT then End
    Go to: 8.
```

End

The computational complexity of this algorithm is O(3NM).

The presented algorithm of consensus proposes a decision to the trader, who does not need to think about the choice of decision generated by Basic Agents and Intelligent Agents, which significantly reduces the time it takes to make a decision. Since a decision is taken on the basis of multiple agents' decisions, it also reduces the risk of taking this decision, because it eliminates the possibility to make an incorrect decision by one of the agents a-Trader system agents.

The verification of the Supervisor strategy is presented in the next section of the article.

IV. EXPERIMENTS

FOREX (Foreign Exchange Market) is the market where one currency is traded for another. It is one of the largest markets in the world. Currencies are traded against one another in pairs. For instance, the quotation EUR/USD (EUR/USD) 1.3465 is the price of the euro expressed in US dollars, meaning 1 euro = 1.3465 dollars. To evaluate the Supervisor performance the pair EUR/USD is chosen from the FOREX market. In the evaluation the following assumptions have been imposed:

1. The minute-by-minute quotations EUR/USD are randomly selected, covering the following periods:
   I. 17-04-2013 hours: 12:47 to 15:00,
   II. 30-04-2013 hours: 18:36 to 23:16,
   III. 08-05-2013 hours: 21:45 to 23:34,
   IV. 09-05-2013 hours: 00:00 to 2:50.
   For instance, Fig. 3 presents a quotation of the pair EUR/USD in period IV.
2. During verification, the Supervisor uses the decisions (signals buy-value: 1, sell-value: -1, remain unchanged-value: 0) generated by program agents, which operate on the basis of a combination of technical analysis indicators (i.e.. agent no. 1 taking decisions on the basis of RSI, Stochastic Oscillator, MACD indicators combination, agent no. 2 – CCI, WILLIAMS, OBV, etc.). Due to the computational complexity and time constraints, the experiment was illustrated in the article by the Supervisor's signals generated by 6 agents.
3. Final Buy-Sell decisions are taken on the basis of the Supervisor's signals (fig. 4).
4. It is assumed that the initial trader capital equals 1000 USD, and that the investment rate of return shall be calculated as the difference between the initial capital and the amount that the investor will have after the last sales in a given period. The rate of return is expressed in (USD).
5. No transaction costs are taken into consideration.
6. Money management – assume that in each transaction, the investor commits 100% of capital. Money management strategy can be set by the user. The investor invests every time 1000 USD - leverage 10:1.
7. Performance evaluation is based on following ratios:
   a) the number of transactions,
   b) gross profit,
   c) gross loss,
   d) total profit,
   e) the number of profitable transactions,
   f) the number of profitable transactions in a row,
   g) the number of unprofitable transactions in a row,
   h) the average coefficient of variation is the ratio of the average deviation of the arithmetic average multiplied by 100% and is expressed:

$$V = \frac{s}{|E(r)|} \cdot 100\,\% \; . \qquad (3)$$

where:
V – average coefficient of variation,
s – average deviation of the rate of return,
E(r) – arithmetic average of the rate of return.

Fig.3 EUR/USD quotations
Source: Own work.

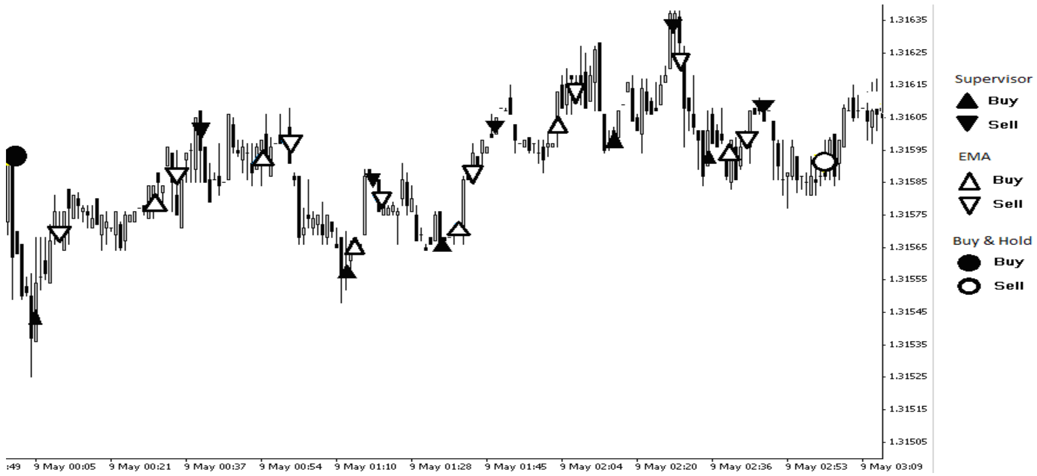

Fig.4 Decisions of Supervisor, Buy-and-Hold and EMA in the period IV
Source: Own work.

i) Value at Risk – the measure known as value exposed to the risk - that is the maximum loss of the market value of the financial instrument possible to bear in a specific timeframe and at a given confidence level [2].

$$VaR=P*O*k \quad (4)$$

where:
P – the initial capital,
O – volatility - standard deviation of rates of return during the period ,
k –the inverse of the standard normal cumulative distribution (assumed confidence level 95%, the value of k is 1,65).

8. The results obtained by the Supervisor have been compared with the passive strategy Buy-and-Hold and the benchmark using EMA.

The test was carried out in the following way:

1. On the basis of the quotation from the first period, each agent referred to when to buy and when to sell a currency EUR/USD.
2. Next, taking into consideration the decisions of all the agents, the consensus was determined.
3. The performance of the Supervisor and benchmarks Buy-and-Hold and EMA are reported.
4. Next, the steps 1 to 4 were repeated using the next periods of the financial time series.
5. In the final stage, the performance ratio values were calculated corresponding to rates of return resulting from all decisions generated by the Supervisor, Buy-and-Hold and EMA strategies (not only of the final rates of return, but with all the rates of return calculated after each sale decision).

Comparison of final capital and rates of return obtained are shown in table 1.

TABLE 1. COMPARISON OF FINAL CAPITAL AND RATES OF RETURN

	Consensus		**B & H**		**EMA**	
period	Rate of return [USD]	Rate of return [%]	Rate of return [USD]	Rate of return [%]	Rate of return [USD]	Rate of return [%]
I.	10,59	0,011	-19,01	-0,019	-29,64	-0,030
II.	19,09	0,019	11,10	0,011	7,68	0,008
III.	4,56	0,005	3,50	0,004	4,71	0,005
IV.	6,84	0,007	-0,23	-0,0002	4,26	0,004
average	10,27	0,010	-1,16	-0,0001	-3,25	-0,0003

Source: Own work.

Summing up the results obtained through the use of the consensus method, in each period, a higher rate of return is shown compared with the decisions generated by the Buy-and-Hold and EMA. It should also be noted that the average rate of return of the Supervisor's decision is positive (profit), while the average rate of return of the Buy-and-Hold and EMA is a negative value (loss).

The performance analysis (table 2) shows that the Supervisor generated a smaller number of transactions than using the EMA, but with the EMA, however, the gross profit from these transactions is higher than the gross profit generated by EMA and Buy-and-Hold.

At the same time, the gross loss generated by the Supervisor is relatively lower in comparison with the benchmarks. It should also be noted that the Supervisor conducted a 93,33% profitable transactions (Buy-and-Hold 50%, EMA 47,06%). Important is also the fact that the Supervisor does not generate a series of unprofitable transactions in a row, but for instance the EMA generated such transactions. Analyzing the risk of decisions, it can be

TABLE 2.
RESULTS OF PERFORMANCE ANALYSIS

Performance ratio	Supervisor - Consensus	B & H	EMA
Number of transactions,	15	4	34
Gross profit	41,54 USD	14,60 USD	27,60 USD
Gross loss	-0,46 USD	-19,24 USD	-40,59 USD
Total profit	41,08 USD	-4,64 USD	12,99 USD
Number of profitable transactions (%)	14 (93,33%)	2 (50%)	16 (47,06%)
Number of profitable transactions in row	8	1	6
Number of unprofitable transactions in row	1	1	6
Average coefficient of variation	6,29%	7,95%	10,51%
Value at Risk	8,26 USD	18,30USD	18,53 USD

Source: Own work

noticed that the use of consensus methods by the Supervisor allows the lowest level of risk investment. The value of Average coefficient of variation equals 6.29%, while for Buy-and-Hold equals 7,95%, and for EMA 10,51%, instead. The Value at Risk of decisions generated by the Supervisor was 8,26 USD, which means that using the consensus method the trader can lose up to 8,26 USD in about a 2 hours period. Regarding Buy-and-Hold and EMA, this value was appropriately 18,30 and 18,53.

The verification of using the consensus method by the Supervisor agent therefore suggested that the decisions supported by the A-Trader system are the decisions which allow the investor to get satisfactory investor's results. It should be noted, of course, that the consensus method will not necessarily always get the highest rate of return. However, it can be assumed that, as a general rule, it allows the investor to obtain a lower level of risk associated with the investment. Note that if an investor had to make the choice which agent has to "listen to", then, assuming that the probability of selection of the agents by the investor is the same, he could more often choose a decision (hint) of an agent that allows one to get a lower rate of return. Besides, the evaluated agents using simple indicators are characterised by the large disparity in rates of return, confirming, for example, the value of the average coefficient of variation of EMA or Buy-and-Hold.

In conclusion, we can say that financial decisions generated by the consensus method allow to get a higher rate of return in comparison to benchmarks such as Buy-and-Hold and EMA, and get a faster determination of the decision, than if the investor takes the decision himself, among the decisions generated by the agents. Currently, due to the turbulent economic environment, investing in financial instruments must be carried out in close to real time. First and foremost, however, the use of consensus algorithms by the Supervisor allows the investor to decrease the level of risk related to financial instrument investing. Therefore, it also increases the level of usefulness of the decisions, and this can bring the user satisfying benefits.

It should be noted that the agents that were used in this experiment applied only to technical analysis indicators. It should be stressed that the A-Trader system gives a possibility of implementing the agents using fundamental analysis, or behavioral analysis. Work on the extension and variety of the agents' knowledge is in progress.

V. CONCLUSION

The first attempts to implement a multi-agent environment proved encouraging. The Supervisor decreased the investment risk by restricting the independent operations of more risk-taking agents for joint decisions of the entire environment. The cooperating agents made profitable decisions more frequently and close the loss-generating positions considerably earlier.

It should be stressed that the goal of multi-agent financial decision support systems, also the A-Trader system, is not only to maximize the rate of return on investment, but also to limit the level of risk associated with this investment. Taking into account the EUR/USD quotation dealt with in the article, it can be concluded that the level of risk is associated with, among other things, the fact that the financial situation of the euro depends on the economic and political situation in many countries. Whereas the dollar depends on a variety of government regulations and the United States engagement in the world economy.

Of the experiment in the article, it can be concluded that the use by the Supervisor of the consensus method makes it possible to lower the level of investment risk in consequence.

This can lead the investor to achieve a satisfactory investment rate of return.

The platform allows the implementation of different, intelligent or behavioral Supervisor strategies. The described multi-agent system makes testing and validating these new algorithms easier by supplying the basic functionalities and data. It enables the concentration of work on constructing new Supervisor strategies without being concerned about the basic data and message supply mechanisms

The A-Trader platform is now in the testing and expansion phase. The number and scope of the applied methods is being continuously expanded. New agents based on the recent methods are created. Of course, to obtain more objective conclusions about the consensus strategy, the tests should be done on a longer periods, with other quotes.

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