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Decision support methods in a competitive environment based on Boyd cycle by means of ontology use

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Abstract. The method of decision making system elaboration in competitive environment based on ontological approach was developed. For scientific modeling of decision support process in competitive environment, mathematical support and methods of domain-specific ontology in the Boyd cycle (OODA – observation, orientation, decision, action) were elaborated.

Key words: decision support system (DSS), ontology, knowledge database, Boyd cycle (OODA), observation, orientation, decision, action, genetic algorithms, expected value, probability.

INTRODUCTION

The effectiveness of modern armed forces largely depends on the professional level of command structure that in its turn is defined by the degree of its automation. Troop control automation can essentially enhance the combat capabilities and shorten the time the supervisory units spend on operation planning and informing their command subordinates. Automatic control system (ACS) of Ukrainian Ground Forces tactical section is a totality of self-dependent bodies and command points that are equipped with computer based decision support systems and means of communication that enable effective control of formations, units and subunits. Decision support system (DSS) is a central element of Automatic control system (ACS). It enables the military operations modeling, development of possible variants based on different criteria and transfer of recommendations to tactical section commanders. It is worth mentioning that the Decision support system (DSS) is functioning in a competitive environment that involves several management entities that compete. Modern approach to scientific modeling of decision support process in a competitive environment (like military) lies in the use of Boyd cycle that presupposes multiple recycling of four consecutive stages: observation, orientation, decision, action. This cycle is also abbreviated OODA. According to Boyd hypothesis – the speed of the cycle and the accuracy of evaluation of its stages provides the advantage over the enemy and leads to the victory in warfare. During warfare modeling we can distinguish several important indexes that directly influence the result. These indexes of ground forces warfare modeling are: distance between troops, manoeuvre characteristics, practicability (motion resistance), target visibility (possibility of target detection), possibility of target destruction, sector of target search, density of suballotmant of fire means on enemy's targets, number of shoots needed to destroy the target (spread characteristics, protection of the target, distance, etc.)

In the majority of cases the value of these indexes directly depends on operational and physical characteristics (OPC) of different types of armament and military equipment as well as the institutional and management structure of formations, units and subunits. That is why reliable software to keep all this information is required. Such information is to be stored in a knowledge database not in an ordinary database, because logical output is very important in the process of warfare modeling and it can be implemented only on the base of knowledge of subject area. As far as the tactical and technical characteristics of weapons and military equipment and organizational and staff structure is based on normative documents, the core for such knowledge database will be the ontology of Ukrainian Ground Forces.

THE ANALYSIS OF RECENT RESEARCHES AND PUBLICATIONS

Research towards the use of ontologies in the development and functioning of information systems, including the DSIS, has begun late last century and is developing intensively. Basic theoretical principles of formal mathematical models of ontology were developed in the works of T. Hruber [1], who proposed to consider ontology as three-dimensional tuple; N. Huarino [2] in his works described methods of ontology building and possible ways of its development; D. Sova introduced the conceptual graphs term [3] and M. Montes-Gomez used it for ontology presentation [4]. Analyzing the works in general we can conclude that research in the development and use of ontologies in the construction of applied information systems is actively developing. These facts show the topicality of the building DSS-related problems based on ontologies as a subject of research [5–8].

Analysis of the main approaches, methods and tools for building DSS and research areas using ontologies shows that the composition of these systems uses not all the possibilities of ontologies, especially during functionality simulation of such systems, although the advantages of ontologies usage in comparison with other methods of constructing knowledge base are obvious since ontologies reflect objective knowledge and serve as a standard of engineering knowledge. In particular, there are some unresolved problems: modeling of decision-making processes and extraction of new knowledge based on ontologies; ontologies filling criteria; assessment of ontologies knowledge novelty and so on [9–11].

The purpose of the article

Development of decision support methods in a competitive environment based on Boyd cycle by means of ontology use.

MATERIALS AND METHODS

Let’s have a closer look at each stage of Boyd cycle in the process of interaction with domain-specific ontology and tasks that arise in this domain (Fig. 1).

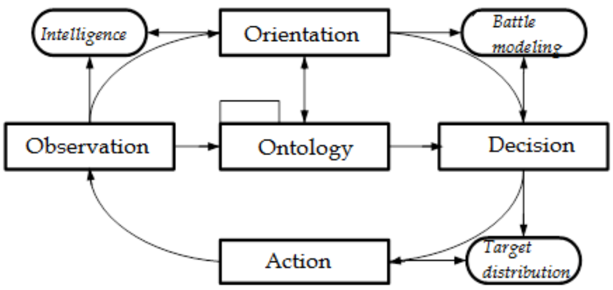

Fig. 1. Stages of Boyd cycle (OODA) and their interaction with ontology

Stage of observation gives the possibility to construct the ontology and to analyze it for relevant information that is needed in next stages of the OODA cycle.

Ontology analysis is done on the basis of intelligence service data. Intelligence officers transfer information concerning enemy’s assets that is found in ontology, information is processed and transferred to the tactical section commander.

Processing of intelligence data looks as follows: Intelligence officers provide messages (generally many-sided) concerning system X; it is required to define the system condition as precisely as possible and distribute the possibility of different conditions. Apart from that, while processing the intelligence data, only reliable messages should be analyzed, that means the conditions’ evaluation should be done in advance $x_1, x_2, ..., x_k$ $P_0(x_1), P_0(x_2), ..., P_0(x_k)$. Let’s call these conditions preliminary to differentiate them from final ones received from intelligence officers.

Apparently, final conditions depend on the set of messages collected by intelligence officers. Let us designate the set of messages by the letter $\tilde{S}$, and the final probability of conditions based on those messages as $P_p(x_1/\tilde{S})$; $P_p(x_2/\tilde{S})$; ...; $P_p(x_k/\tilde{S})$. These possibilities are imaginary possibilities of conditions $x_1, ..., x_k$, calculated on the event that the intelligence provided the set of messages $\tilde{S}$, that are calculated with the help of Bayes' formula:

$$P_p(x_i/\tilde{S}) = \frac{P_0(x_i)P(\tilde{S}/x_i)}{P_0(x_1)P(\tilde{S}/x_1)+...+P_0(x_i)P(\tilde{S}/x_i)+...+P_0(x_k)P(\tilde{S}/x_k)}, \quad (1)$$

where $P(\tilde{S}/x_1)$ is a possibility of the set of messages $\tilde{S}$, if a system is in a condition x_1; $P(\tilde{S}/x_2)$ is a possibility of the set of messages , if a system is in a condition x_2, etc.

If you do not have any preliminary data on the system condition, the possibilities can be defined as equal: $P_0(x_1) = P_0(x_2) = ... = P_0(x_k) = \frac{1}{k}$.

Let us presume that an intelligence officer delivers a message $\tilde{x}_1$. According to Bayes' formula (1) the possibility of condition x_1 equals:

$$P_p(x_1/\tilde{x}_1) = \frac{P_0(x_1)P(\tilde{x}_1/x_1)}{P_0(x_1)P(\tilde{x}_1/x_1)+P_0(x_2)P(\tilde{x}_1/x_2)}.$$

Apparently, $P_p(x_2/\tilde{x}_1) = 1 - P_p(\tilde{x}_1/x_1)$. Let us presume that an intelligence officer delivers a second message $\tilde{x}_2$. Than:

$$P_p(x_1/\tilde{x}_2) = \frac{P_0(x_1)P(\tilde{x}_2/x_1)}{P_0(x_1)P(\tilde{x}_2/x_1)+P_0(x_2)P(\tilde{x}_2/x_2)}.$$

If an intelligence officer does not deliver any message, than:

$$P_p(x_1/\tilde{x}_0) = \frac{P_0(x_1)P(\tilde{x}_0/x_1)}{P_0(x_1)P(\tilde{x}_0/x_1)+P_0(x_2)P(\tilde{x}_0/x_2)}.$$

Intelligence is the most important element that guarantees advantage in warfare. Tactical intelligence is aimed at creation of favorable conditions to start a battle in an organized and well-timed manner and successful warfare conducting. That is why it is needed to develop software to transfer the information to staff quickly and effectively as well as to generalize the data concerning effective combat strength, location and enemy forces status, nature and intention of their action, strengths and weaknesses, level and type of equipment. To collect and process intelligence data we have developed an Android application “Military Intelligence” (Chapter 4).

On the **stage of orientation** the strategy of action is defined. For this purpose a modulus of simulation modeling of a battle was designed. It is described in details in Chapter 4. This chapter describes the software the modulus functions on.

In the process of warfare modeling we can distinguish several parameters that influence the result. The parameters for warfare modeling for ground forces are: distance between troops, performance characteristics of mechanized infantry, land: practicability (motion resistance), target visibility (possibility of target detection), possibility of target destruction, sector of target search, density of suballotmant of fire means on enemy's targets, number of shoots needed to destroy the target (spread characteristics, protection of the target, distance, etc.) In the majority of cases the value of these indexes directly depends on operational and physical characteristics (OPC) of different types of armament and military equipment as well as the institutional and management structure of formations, units and subunits. That is why reliable software to keep all this information is required.

To determine which elements should be stored in ontology of knowledge database in decision support system (DSS), let us analyze the mathematical models that are used in the process of warfare modeling.

Mathematical warfare model is a two set model $Q=\{q_1,q_2,...,q_n\}$ and $U=\{u_1,u_2,...,u_m\}$, that define the qualitative and quantitative structure of belligerent powers. For each element $q_i \in Q$ exists a random multidimensional function $z_i(t)=z\left(z_{i1}(t),z_{i2}(t),...,z_{ir(i)}(t)\right)$ for $T_0 \le t \le T_1$, where T_0 i T_1 respectively signify the moments of the start and end of the battle. Random functions $z_{i1}(t),z_{i2}(t),...,z_{ir(i)}(t)$ are referred as parameters of the element q_i, l – implementation of a random function $z_i(t)$: $z_i^l(t)=z_i\left(z_{i1}^l(t),z_{i2}^l(t),...,z_{ir(i)}^l(t)\right)$. Random function section $z_i(t)$ in a set time $T_0 \le t_z \le T_1$ is called the status of element q_i and is designated as $C_i(t_z)$. Vector $z_i^l(t_z)=\left(z_{i1}^l(t_z),z_{i2}^l(t_z),...,z_{ir(i)}^l(t_z)\right)$ sets the condition of element q_i in t_z for the 1st implementation and is marked as $C_i^l(t_z)$. Totality $\{C_i^l(T_0)\}$ for all $i=1,2,...,n$ sets the initial status of elements Q for the 1st implementation. Similarly other elements are described U_j $(j=1,2,...,m)$ and corresponding marks are entered:

$$x_j(t)=x_j\left(x_{j1}(t),x_{j2}(t),...,x_{jr(j)}(t)\right),$$

$$x_j^l(t)=x_j\left(x_{j1}^l(t),x_{j2}^l(t),...,x_{jr(j)}^l(t)\right),$$

$$D_j(t_z)=x_j(t_z)=\left(x_{j1}(t_z),x_{j2}(t_z),...,x_{jr(j)}(t_z)\right),$$

$$D_j^l(t_z)=x_j^l(t_z)=\left(x_{j1}^l(t_z),x_{j2}^l(t_z),...,x_{jr(j)}^l(t_z)\right).$$

Totality $\{D_j^l(T_0)\}$ for all $j=1,2,...,m$ is called the initial condition of a belligerent power U for the 1st implementation, and totality $\{D_j^l(T_1)\}$ is an objective result of the battle for belligerent power U for the 1st implementation. $\{C_i^l(T_1)\}$ and $\{D_j^l(T_1)\}$ together are called objective result of the battle for the 1st implementation, and $\{C_i^l(T_0)\}$ and $\{D_j^l(T_0)\}$ the initial condition of a battle for the 1st implementation.

As parameters for chosen elements of the battle the random functions of real number argument *t* can be taken: $h_1(t)$ – combat effectiveness; $h_2(t)$ – military position; $h_3(t)$ – speed; $h_4(t)$ – nature of action; $h_5(t)$ – ammunition number. Detailed models of warfare that were used in the modulus of simulation modeling are described in the book "Mathematical models of warfare" (Математичні моделі бойових дій) edited by P. N. Tkachenko.

To determine the importance of targets the model of adaptive ontology designed by V. V. Lytvyn is used [12–14]. The importance of target is measured by the damage caused as a result of its destruction. The gradation of targets was determined after a survey of military sphere experts that were asked to value the importance of ontology elements on 10 point scale (1 – the important target – bullet pump, 10 – command post brigade) (1 – the importance of machine gun target, 10 – the importance of team CP target). The importance of ontology element that sets the enemy's target is calculated as arithmetical mean of experts evaluation, that is $W \in [1,10]$. Then the enemy's most important target, as an ontology element, is calculated with a help of the following formula:

$$C_{Z^*}=\arg\max_{C_Z}\left(\sum_{C_i \to C_Z} W_{C_i}+W_{C_Z}\right). \tag{2}$$

Decision-making is the third stage of the OODA cycle. If EP managed to shape only one real plan up to this stage, than the decision is made whether to implement this plan or not [15–16].

While improving the decision-making stage we used target assignment problem. Target assignment is an operation which consists in assignments of a certain target to a certain fire weapon. It is necessary to find optimal (best) target assignment by assigning to each cannon a certain target at which it should shoot (however it is possible that one target will be attacked by several cannons).

May we have *n* means of destruction in our disposal and we need to attack a dispersed group which consists of *N* targets. Each means of destruction can make only one shoot and basically can shoot at each target, but with different effectiveness. Probability of hitting ***j***-target by ***i***-means of destruction is set and equals P_{ij}. In order to determine these probabilities we should use tables from regulations, which are saved in the ontology of the Ukrainian Ground Forces.

Probability data destruction of enemy targets a certain way, taken from an ontology based on analysis of input parameters (appearance, permeability, speed, combat effectiveness, the weather conditions).

It is necessary to find optimal (best) target assignment by assigning to each means of destruction a certain target at which it should shoot (however it is possible that one target will be attacked by several means of destruction). Such task is called target assignment $n \times N$.

In order to solve a problem of target assignment, first of all it is necessary to choose a performance indicator. Depending on the shooting conditions such indicator can be:

1) mathematical expectation of affected targets number (probability that in the group at least a given number of targets will be affected);

2) probability that each and every target will be affected, etc.

Indicator of target assignment effectiveness according to mathematical expectation is variable $M_n = M[X_n]$, where a random variable X_n is a number of targets affected.

During shooting at the group target the average number of affected targets equals to sum of probabilities of certain basic targets (units) affection: $M_n = W_1 + W_2 + ... + W_N$, where W_1 – probability of the first target affection; W_2 – probability of the second target affection; W_N – probability of N-target affection. Thus we receive a task:

$$M_n = \sum_{j=1}^{N} W_j \to \max . \qquad (3)$$

Therefore, during the target assignment according to mathematical expectation it is necessary to assign means of destruction to their targets in such a way that the sum of probabilities reached a maximum. The most elementary method to make such assignment is a brute force collision: all possible variants of cannons assignment to targets are searched and one of them is selected whereby the sum of the probabilities reaches a maximum. Computational complexity of such algorithm is exponential and number of possible variants of target assignment equals A_N^n. If a number of possible variants is not very large, this search is possible to perform. However in practice a number of targets and means of destruction is rather considerable. That is why in order to solve a task (3) it is proposed to use artificial intelligence methods, in particular genetic algorithms. In our case formula (3) acts in the quality of fitness function. If a number of means of destruction is much less than a number of targets $(n \prec N)$, targets are ranked in advance according to formula (2).

For the realization of the proposed approach we chose relational database system (in particular MySQL), which contains the information about our available means of destruction, proved enemy targets and probability matrix of destroying targets by a certain fire weapon. Chromosome is a vector, where the number of vector element coincides with a key of means of destruction in database, and the meaning of element coincides with a key of a target in database.

The best solution is considered to be a chromosome with the biggest value of fitness function.

For the purpose of modeling a certain number of chromosome generations were chosen. The experimental results showed that during generation of 30 breed the best chromosome close to the optimum target assignment was find. Developed target assignment module on the basis of genetic algorithms is a part of DSS.

The main advantage of proposed approach is a considerable reduction of complexity of target assignment algorithm. Complexity of a complete enumeration is exponential, and complexity of genetic algorithm is linear. Thus the process of decision-making is much accelerated. This is especially important when the events concerning target assignment take place in the real time. Although received solution of target assignment is not always an optimal one, it is close to optimal and time advantage of the solution receiving is considerable.

Action is the final stage of the cycle, which presupposes practical realization of the chosen idea or plan.

Summing up everything previously mentioned, in the work a model of Boyd cycle with the usage of ontology in the form of Moore automatic weapon (Fig. 2) was elaborated.

At the Fig. 2 indicates: s_0 – initial state ("Observation" stage), s_1 – "Orientation" stage, s_2 – "Ontology editing", s_3 – "Search of relevant knowledge", s_4 – "Decision" stage, s_5 – "Action" stage; x_1 – data absent in ontology, x_2 – data about enemy, x_3 – ontological data (x_3' – for a decision, x_3'' _ for an action), x_4 – environment assessment, x_5 – situation modeling, x_6 - data synthesis, x_7 – data analysis, x_8 – decision assessment, x_9 – data collection, x_{10} – proposed solution, x_{11} – ontology editing (new knowledge), x_{12} – environment.

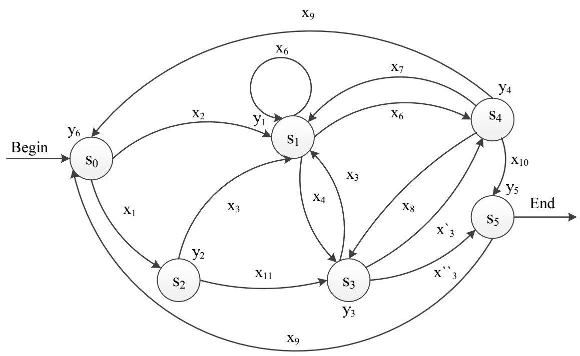

Fig. 2. Moore automatic machine of Boyd cycle with the usage of ontology

THE MAIN RESULTS OF THE RESEARCH

Sphere of military technology is characterized by the absence of regulatory established definitions and strict classification of technologies. Military technologies are constantly developing; this is reflected in expanding and changing conceptual system.

Elaboration of formal ontology, which includes axiomatic component, for such domain poses an extremely difficult task. Sphere of military technology is a complex-structured sphere that includes abstract, general notions as well as applied terminology, which contains notions on the specific implementation of military technologies. Four main levels of the ontological model of military technologies structure can be established. First level is anthology of knowledge presentation. Goal of the first level is to create a language for specification of lower level ontologies. Since sphere of military technologies is a subclass of technology sphere, relevant ontology of the upper level was introduced. Upper level ontology can be used as a basis for elaboration of ontologies of different domains. It describes main notions in the sphere of technologies such as “technology”, “knowledge”, “technofact”, “production technology”, “dual technology”, “product”, etc. [17–31].

Third level includes ontology of military technologies domain. Main concepts of the military technologies domain are: “military technology”, “weaponization technology”, “weapon production technology”, “basic military technology”, “critical military technology”, “list of basic and critical military technologies”, “basic military technologies development program”.

Applied ontology of military technology, the forth level constituent, describes a plurality of military technology implementations. It contains specific information – concepts and relations, which reveal peculiarities of certain types of weapon and military technology (laser weapon, reactive armor, all-hypersonic platform, navigation system, etc.)

Domain terms in a given case are: combat vehicles, cannons, cannon artillery projectile, etc. The connections between terms are: “has a projectile”, “has a canoon”, etc. (Fig. 3).

In order to increase efficiency of possible decisions in ontology, the knowledge of experts is presented (generals, colonels of Ukrainian Ground Forces) concerning the behavior in certain situations by means of descriptive logic (DL). For example, an expert rule “to bring down fire of our artillery to man-portable air defense system of an enemy during landing of our troops from helicopter on the territory x, if the distance to man-portable air defense system of the enemy is less\equals y” on the DL language in our ontology is presented in the following way: (Landing (Troops, ?x)) – (Location (man-portable air defense system of an enemy, ?x) ≤ ?y) → Bring down fire (Our Artillery, man-portable air defense system of an enemy).

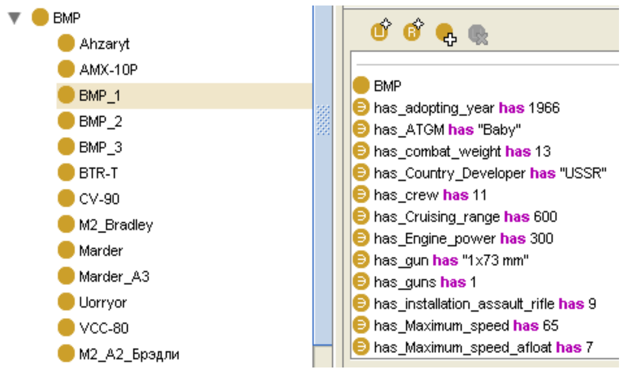

Fig. 3. Ontology fragment and determination of its individual elements

On the basis of developed approach DSS was elaborated. We experimentally proved an efficiency of elaborated DSS, which allowed to reduce the time spent by authorities on the operational planning and task bringing to subordinates in two; optimization of organizational and staff structures, joints, units and subunits of Ukrainian Ground Forces; improvement of operative and combat training of Ukrainian Ground Forces.

CONCLUSIONS

This work containes soluation of important scientifically-applied task of developing methods and tools for building support decision systems in a competitive environment (military area) using ontological approach and efficiency of such systems which is achieved through the use of developed mathematical and software based on the use of ontologies in these systems and adapting to the specific problems of ontology domain. The expediency of development of mathematical models, methods and tools for support decision in a competitive environment based on Boyd loops using ontological approach in those subject areas where knowledge is explicit. That subject area is a military sphere. The model based on hinge Boyd Moore automaton. State machine loops are the stages Boyd and filling processes, ontology editing and search relevant knowledge ontology. Determined the possible transitions between states of the machine and transfer parameters between them. To simulate the process of support decision in a competitive environment developed mathematical software and methods of using domain ontology in four stages loops OODA (observation, orientation, decision, action). So for the military on a stage “Observations” intelligence domain ontology analyzes of determination of the strengths and weaknesses of the enemy. At the stage of “orientation” ontological data used for simulation of the possible course of the battle and for optimal positioning their forces. For stage “Resolution” distribution targets developed a method based on genetic algorithms, which helped to reduce the computational complexity of finding effective distribution targets. Ontology expertise based on descriptive logic is presented to increase to increase the effectiveness of possible solutions.

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