# Ontology Using for Decision Making in a Competitive Environment

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**Abstract.** A method of decision making system elaboration in competitive environment based on ontological approach was developed. The models based on a hinged Boyd-Moore automaton. State machine loops are the stages Boyd and filling processes, ontology editing and a search of relevant knowledge ontology. Possible transitions between the states of the machine and transfer parameters between them were determined. For a quantitative modeling of decision support process in a competitive environment, mathematical support and methods of domain-specific ontology in the Boyd cycle (OODA – observation, orientation, decision, action) were elaborated. Thus, for the military at an "Observations" stage intelligence domain ontology determining of the strengths and weaknesses of the enemy. At the stage of "orientation", ontological data are used for simulation of possible realizations of the battle and for optimal positioning of the forces. For "Resolution" stage, target distribution was developed using 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 the effectiveness of possible solutions.

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

## 1 Introduction

The effectiveness of modern armed forces largely depends on the professional level of command structure that, in turn, is defined by the degree of its automation [1]. Troop control automation can essentially enhance the combat capabilities and shorten the time 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 [2]. Decision Support System (DSS) is a central element of ACS. It enables military operations modeling, development of possible variants based on different criteria and transfer of recommendations to tactical section commanders. It is worth mentioning that a DSS is functioning in a competitive environment that involves several management entities that compete [3]. Modern approach to scientific modeling of decision support process in a competitive environment (like the military) one lies in the use of Boyd cycle that presupposes multiple recycling of four consecutive stages: observation, orientation, decision, and action [4]. This cycle is also abbreviated OODA. According to Boyd's hypothesis – the speed of the cycle and the accuracy of evaluation of its stages provide the advantage over the enemy and leads to the victory in warfare. When modeless warfare, we can distinguish between several important indexes that directly influence the result. These indexes of ground forces warfare modeling are: distance between troops, maneuver characteristics, practicability (motion resistance), target visibility (possibility of target detection), possibility of target destruction, sector of target search, density of fire means suballotmant on enemy's targets, number of shoots needed to destroy the target (spread characteristics, protection of the target, distance, etc.) [5-13].

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 save all this information that 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 can only be implemented on the base of knowledge of subject area. As far as the TTX OBT and organizational and staff structure is based on normative documents, the core for such knowledge database will be the ontology of Ukrainian Ground Forces [14]. The goal is to develop decision support methods in a competitive environment based on Boyd cycle by means of ontology use.

## 2 Materials and methods

Let us 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).

**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.

The task of intelligence data processing is summarized as follows: intelligence officers provide messages (generally many-sided) concerning system $X$; it is required to define the system condition as precise 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 $x_1, x_2,..., x_k$ in $P_0(x_1),\ P_0(x_2), \cdots, P_0(x_k)$.

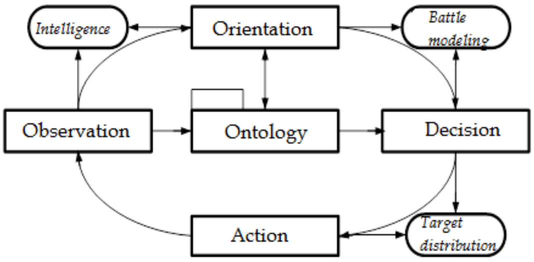


**Fig. 1.** Stages of Boyd cycle (OODA) and their interaction with ontology

Let us call these conditions preliminary ones to distinguish them from final ones received from intelligence officers. Apparently, final conditions depend on the set of messages collected by intelligence officers. Let us denote the set of messages by the letter $\tilde{S}$, and the final probability of conditions based on those messages as $P_p(x_1/\tilde{S}); P_p(x_2/\tilde{S}); \cdots;\ P_p(x_k/\tilde{S})$. These possibilities are conditional 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

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

where $P(\tilde{S}/x_1)$ is a probability of the set of messages $\tilde{S}$ if a system is in state $x_1$; $P(\tilde{S}/x_2)$ is a probability of the set of messages if a system is in state $x_2$, etc. If no have any preliminary information on the system state are available, the conditions can be defined as equal:

$$P_0(x_1) = P_0(x_2) = ... = P_0(x_k) = \frac{1}{k}\cdot$$

Let us assume that an intelligence officer delivers a message $\tilde{x}_1$. According to Bayes' formula (1), the probability of state $x_1$ equals to

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

Obviously, $P_p(x_2/\tilde{x}_1) = 1 - P_p(\tilde{x}_1/x_1)$. Assume that an intelligence officer delivers a second message $\tilde{x}_2$. Then,

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

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 conduction. That’s why it is needed to develop software to transfer the information to the units 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”.

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 section 4. This section describes the software the modulus functions on.

In the process of warfare modeling, we can distinguish between several parameters that influence the result. The parameters for warfare modeling for ground forces are the distance between troops, performance characteristics of mechanized infantry, the terrain: 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 shots 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 is required to store and process all this information.

To determine which elements should be stored in ontology of knowledge database in 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 $q_i\in Q$, there exists a random multidimensional function $\zeta_i(t)=\zeta\left(\zeta_{i1}(t),\zeta_{i2}(t),...,\zeta_{ir(i)}(t)\right)$ for $T_0\le t\le T_1$, where $T_0$ i $T_1$ respectively denote the start and the end periods of the battle, respectively. Random functions $\zeta_{i1}(t),\zeta_{i2}(t),...,\zeta_{ir(i)}(t)$ are referred to as parameters of the element $q_i$, $l$ – implementation of a random function $\zeta_i(t)$: $\zeta_i^l(t)=\zeta_i\left(\zeta_{i1}^l(t),\zeta_{i2}^l(t),...,\zeta_{ir(i)}^l(t)\right)$. Random function section $\zeta_i(t)$ in a time set $T_0\le t_z\le T_1$ is called the status of element $q_i$ and is denoted as $C_i(t_z)$. The vector $\zeta_i^l(t_z)=\left(\zeta_{i1}^l(t_z),\zeta_{i2}^l(t_z),...,\zeta_{ir(i)}^l(t_z)\right)$ stands for the condition of element $q_i$ in $t_z$ for the 1[st] implementation and is written as $C_i^l(t_z)$. The collection $\{C_i^l(T_0)\}$ for all $i$=1,2,…,$n$ describes the initial status of elements $Q$ for the 1[st] implementation. Similarly, other elements are given by $U_j(j=1,2,...,m)$ and corresponding marks are entered:

$$\xi_j(t)=\xi_j\left(\xi_{j1}(t),\xi_{j2}(t),...,\xi_{jr(j)}(t)\right),\ \xi_j^l(t)=\xi_j\left(\xi_{j1}^l(t),\xi_{j2}^l(t),...,\xi_{jr(j)}^l(t)\right),$$
$$D_j(t_z)=\xi_j(t_z)=\left(\xi_{j1}(t_z),\xi_{j2}(t_z),...,\xi_{jr(j)}(t_z)\right),$$
$$D_j^l(t_z)=\xi_j^l(t_z)=\left(\xi_{j1}^l(t_z),\xi_{j2}^l(t_z),...,\xi_{jr(j)}^l(t_z)\right).$$

The collection $\{D_j^l(T_0)\}$ for all $j$=1,2,…,$m$ is called the initial condition of a belligerent power $U$ for the 1st implementation, and the collection $\{D_j^l(T_1)\}$ is an objective result of the battle for belligerent power $U$ for the 1st implementation. $\{C_i^l(T_1)\}$ and $\{D_j^l(T_1)\}$ are called the together 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 following random functions of a real argument $t$ can be chosen: $\eta_1(t)$ – combat effectiveness; $\eta_2(t)$ – military position; $\eta_3(t)$ – speed; $\eta_4(t)$ – nature of action; $\eta_5(t)$ – ammunition amount. Detailed models of warfare that were used in the modulus of simulation modeling are described in the book "Mathematical models of warfare" edited by P. Tkachenko. To determine the importance of targets, the model of adaptive ontology designed by V. Lytvyn is used [14-18]. 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 assess the importance of ontology elements on a 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 target is calculated as the usage of experts evaluation, that is $W\in[1,10]$. Then, the enemy's most important target, as an ontology element, is calculated via the following formula:

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

**Decision-making** is the third stage of the OODA cycle. If CP managed to shape only one real plan up to this stage, the decision is made whether to implement this plan or not. 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 the 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). Assume here are $n$ means of destruction at our disposal and we need to attack a dispersed group which consists of $N$ targets. Each of the means of destruction can make only one shot and basically can shoot at each target, but with different effectiveness. Probability of hitting the $j$-th target by the $i$-th means of destruction equals to $P_{ij}$. In order to determine these probabilities, we use tables from regulations, which are given 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, weather conditions). It is necessary to the find optimal (best) target assignment by assigning to each means of destruction a certain target at which it should aim (however, it is possible that one target will be attacked by several means of destruction). Such task is called an $n \times N$ target assignment. In order to solve a problem of target assignment, first of all, it is necessary to choose a performance indicator. Depending on shooting conditions, such indicator can be:

- the expectation of affected targets number (that doesn't team to be equal to the expectation);
- 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 the random variable $X_n$ is the number of targets hit. During shooting at the group target, the average number of hit targets equals to the 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 hitting; $W_2$ – probability of the second target hitting; $W_N$ – probability of $N$-target hitting. Thus we obtain a task:

$$M_n = \sum_{j=1}^{N} W_j \to \max \tag{3}$$

Therefore, the target assignment with respect to the expectation, it is necessary to assign means of destruction to their targets in such a way that the sum of probabilities reaches a maximum. The simplest method of performing such an assignment is the brute force full search: all possible variants of cannon assignment to targets are searched and the one rendering the sum of the probabilities maximal is selected. Computational complexity of such algorithm is exponential and the number of possible combinations of target assignments 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 problem (3), it is proposed to use artificial intelligence methods, in particular genetic algorithms. In our case, equation (3) acts as a 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 equation (2). For realization of the proposed approach, we chose relational database system implemented in MySQL, which contains 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 is the key of means of destruction in database, and the meaning of element is the key of a target in the database. The optimal solution is than the chromosome with the largest value of fitness function. For modeling purposes, a certain number of chromosome generations were chosen. Experimental results showed that during generation of 30 breeds the best chromosome close to the optimum target assignment was find. The target assignment module developed on the basis of genetic algorithms is a part of DSS.

The main advantage of the proposed approach is a considerable reduction of complexity of target assignment algorithm. Where the complexity of a complete enumeration is is exponential; the complexity of the genetic algorithm is linear with respect to the number of iteration. Thus, the process of decision-making is significantly accelerated. This is especially important when the events concerning target assignment take place in the real time. Although there is received solution of target assignment is not always optimal, it is close to the optimal one and the time advantage when computing the problem 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, a model of Boyd cycle with the usage of ontology in the form of Moore automatic weapon (Fig. 2) was elaborated. Figure 2 displays: $s_0$ – 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.

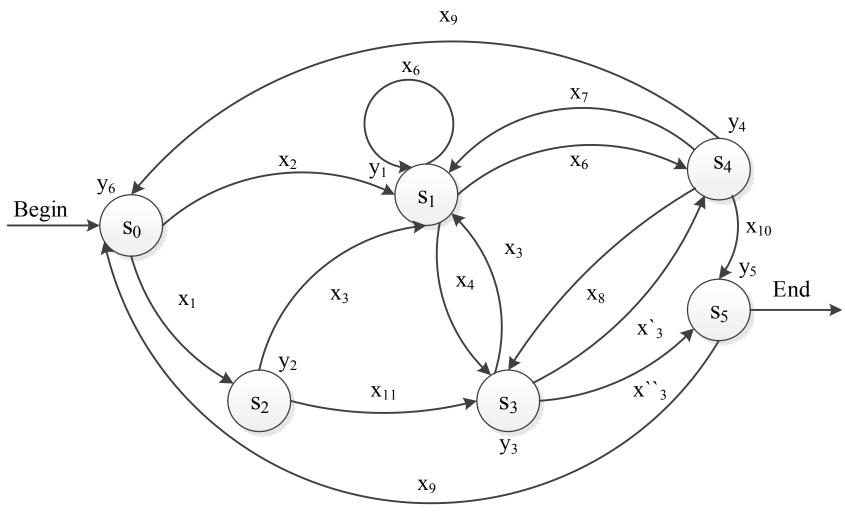


**Fig. 2.** Moore automatic machine of Boyd cycle with the usage of ontology

The area of military technology is characterized by the absence of regions regulatory established definitions and strict classification of technologies. Military technologies are constantly developing; this is reflected in expanding and changing conceptual scheme for system. Elaboration of formal ontology, which includes in axiomatic component, for such domain conditions an extremely difficult problem. Military technology is a complex-structured sphere that includes abstract, general notions as well as applied terminology, which contains concepts in the specific implementation of military technologies. Four main levels of the ontological model of military technologies structure can be established. The first level is the anthology of knowledge presentation. The goal of the first level is to create a language for specification of lower level ontology. Since sphere of military technologies are a subclass of technology, 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 concepts in the sphere of technologies such as "technology", "knowledge", "technofact", "production technology", "dual technology", "product", etc. The 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 the set of military technology implementations. It contains specific information – concepts and relations, which reveal peculiarities of certain types of weapon and military technology (laser weapons, reactive armor, all-hypersonic platform, navigation systems, etc.) [6-13]. 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).

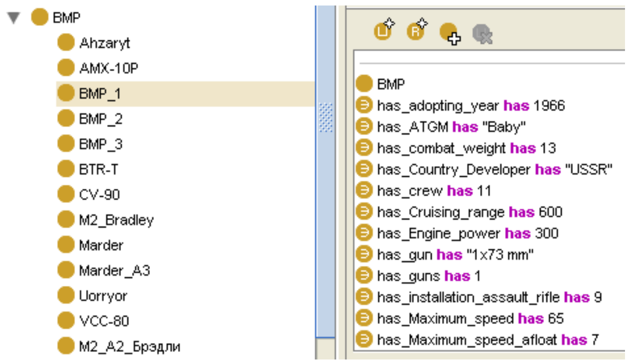


**Fig. 3.** Ontology fragment and determination of its individual elements

In order to increase the efficiency of possible decisions in ontology, the knowledge of experts is presented (generals and 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 or equal to 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). On the basis of the approach developed, a DSS was elaborated. We experimentally proved the efficiency of our DSS, which allowed to reduce the time spent by the Army leaders on the operational planning and task communication to subordinates; optimization of organizational and staff structures, joints, units and subunits of the Ukrainian Ground Forces [19-26]; improvement of operative and combat training of the Ukrainian Ground Forces [27-40].

## 3 Conclusions

This work contains a solution of the important scientifically and practically task of developing methods and tools for building support decision systems in a competitive environment (military area) using ontological approach. The efficiency of such systems which is achieved through the use of mathematical and software developed based on the use of ontology in these systems and adapting to specific problems of the ontology domain. The expediency of development of mathematical models, methods and tools for support decision in a competitive environment is based on Boyd loops using ontological approach in those subject areas where knowledge is explicit. One of such subject areas is the military sphere. The models based on a hinged Boyd-Moore automaton. State machine loops are the stages Boyd and filling processes, ontology editing and a search of relevant knowledge ontology. Possible transitions between the states of the machine and transfer parameters between them were determined. To simulate the process of decision support in a competitive environment mathematical software and methods of using domain ontology in four stages loops OODA (observation, orientation, decision, action) were developed. Thus, for the military at an “Observations” stage intelligence domain ontology determining of the strengths and weaknesses of the enemy. At the stage of “orientation”, ontological data are used for simulation of possible realizations of the battle and for optimal positioning of the forces. For “Resolution” stage, target distribution was developed using 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 the effectiveness of possible solutions.

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