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ITJ

ISSN 1812-5638

INFORMATION TECHNOLOGY JOURNAL

ANSInet
Asian Network for Scientific Information
308 Lasani Town, Sargodha Road, Faisalabad - Pakistan

Information Technology Journal 13 (11): 1878-1882, 2014
ISSN 1812-5638 / DOI: 10.3923/itj.2014.1878.1882
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A Research on Battlefield Situation Assessment with Bayesian Games

[1]J.J. Yan, [2]Y. Wang and [3]H. Cheng
[1]Business School, Sichuan University, Chengdu, 610065, China
[2]Southwest China Institute of Electronic Technology, Chengdu, 610036, China
[3]School of Management Science, Chengdu University of Technology, Chengdu, 610059, China

Abstract: The fusion and transmission of information in decision level are helpful for battle decisions. The existing research was focused on the underlying information fusion and lack of the behavior analysis between participants. So in this study, Bayesian game is introduced to situation assessment to analyze the commander's subjective thinking process in the situation assessment. Based on the deep analysis of the content and function of situation assessment, a kind of high-level framework of situation assessment is put up and the equilibrium state is got. The validity of the method is verified by a simulation. This study has great significance in the developing the battlefield situation assessment theory.

Key words: Situation assessment, Bayesian game, influence diagrams, data fusion

INTRODUCTION

A large number of uncertainties in the battlefield makes the fight decision-making more difficult. To convert information advantages into decision advantages as soon as possible, the greater challenge is how to fuse data effectively in the decision-making level. Situation assessment is a kind behavior of reasoning in the decision-making level, which receives the result of a data fusion and extracts the perception of current military posture as accurate and complete as possible. Thus, Situation assessment can identify the intention of the enemy and the battle plan and provide direct support for the command members of decision-making.

Dempster-Shafer argument theory and set pair analysis method are often used in situation assessment (Wang and Kou, 2007; Chen *et al*., 2004). They are not enough in evaluation and understanding of the battlefield. So, the Cloud-gravity-center was introduced to solve the battlefield situation assessment and the proposed solution is proved to be effectiveness through the simulation (Feng *et al*., 2011).

Bayesian Network is an effective tool for uncertainty reasoning and data analysis. It was applied in the battlefield situation assessment (Zhang *et al*., 2008). But it has some defects because it is discrete. Zhao *et al*. (2010) introduced the Dynamic Bayesian Network in the war situation assessment, built continuous variable model and used Graph model of kalman filter method to predict the continuous state Dynamic Bayesian Network.

The current data fusion researches confine in the low level. In terms of the issues to be addressed or processing method, the low-level data fusion and high-level situation assessment are very different. In the low-level, the fusion mainly uses the complex sensor technology and mathematical methods to solve the classification problem. And the basic problem of high-level fusion is to give the right information at the right time to the right people, which is actually a process of data collection, classification and transformation. To do this, it is important to further understand the cognitive processes and on the other hand it is necessary to find new ways for real-time information integration at different level. This study introduces the game theory into situation assessment and raises a high-level situation assessment framework to reflect subjective thinking after deep analysis of the situation assessment of contents and functions. In the same time, it does the situational deduction given battlefield scenario through simulation.

MATERIALS AND METHODS

Subjective situation assessment: Endsley described situation assessment as the intelligent processing of environment (progress, status and interrelation) and other related areas, is the internal understanding progress of the decision maker (Endsley and Garland, 2000). This study defined situation assessments as: Situation assessment is the understanding of elements of the environments and the prediction of their future changes in certain time and space.

Corresponding Author: H. Cheng, School of Management Science, Chengdu University of Technology, Chengdu, 610059, China

As Endsley only gave the definition from one aspect, some scholars gave their points on this view. Artman (2000) saw situation assessments as a decision making system, an interaction processing of individual from different environments, rules, culture and military background. Artman (2000) studied situation assessments from the perspective of intelligent body and saw it as the initiative to build a multiple intelligence model. There are two advantages of this view: Firstly, in subjective situation assessment model, sensors and other resources are more efficiently used, thus can make sure that data obtained are well used by multiple decision makers. Secondly, from the subjective point of view, the situation elements are more likely to be shared among policy makers in order to promote their collaboration. People are devoted to collect external sensors to obtain various data and integrate various databases to improve the effect of situation assessment objectively. However, situation assessments are actually depend on the human mind and feeling, a subjective thinking process more depends on policy-makers thinking ability, which cannot be observed. It is not only a rational analysis of the alternatives. General situation assessments should contain.

Physical entities: Include the observation and state estimation of different physical elements such as vehicles, soldiers, weapons and sensors.

Friendly decisions: The entire organization is dynamic and flexible structure and makes full use of low-level convergence results in order to get potential intentions, plans, results and effectiveness from friendly side, to get the real decision, which plans to be adopted finally.

Enemy decisions: It include the organizational decisions and intentions from enemy side. Although, it is similar with friendly decision-making and evaluation, but is uncertain because of enemy decision is mainly rely on inference.

The game: Enemy decision-making assessment will depend on friendly side ultimately and vice versa. This game situation needs to be processed in the command and control. This dependency is considered as the high level of situation assessment, is also the main research content of this chapter.

From above analysis, it can be seen that the auxiliary decision-making tools should be used on top of game theory in data fusion. But so far, there is not lot research work of this field.

Situation assessment based on bayesian game

The bayesian networks and influence diagrams: The element used to reason uncertainty is a random variable. When the number of random variables is large, the effective calculation of joint distribution generally is particularly difficult. In this case, the Bayesian network B = <G, P> as a kind of data structure provides a compact representation for a large number of dependent random variables which joint probability. Evidences gave for some variables, through effective reasoning to update the parameters in the chart. Random variables are obtained by the topology of the Bayesian network, the assumption of independence between random variables is set on the Bayesian networks, which is the only identified a probability distribution:

$$P(V) = P(V_i|pa(V_i))$$

which greatly simplifies the calculation. Bayesian networks have been widely used in the situation assessment and obtained the good results. According to the rules of probability chain, joint distribution of random variables listed as follows:

$$P(V) = P(V_1, V_2, ..., V_n) = \prod_{i=1}^{n} P(V_i|V_1, V_2, ..., V_{i-1})$$

Influence diagram is a natural extension of Bayesian network, including the decision node, utility node and opportunities. Decision makers take the action based on selected decision node, value node to calculate the value of decision making, show the problem in the decision progress of individual decision maker. By using the dynamic programming method to evaluate diagrams influence, maximum utility can be got in decision sequence. When designing situation assessment, expressing the knowledge, causality and the uncertainty, different actions need to be taken to reason and observe on the expected utility of action (Brynielsson and Arnborg, 2004). Influence diagram model of military command and control system is shown as Fig. 1. The

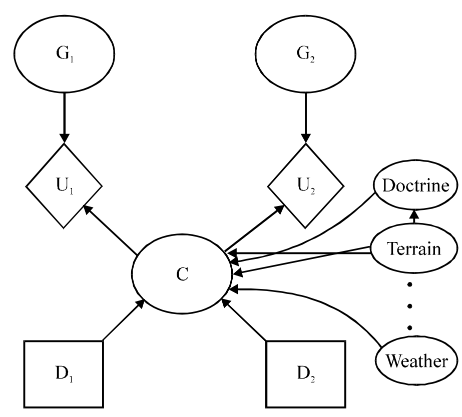

Fig. 1: The influence diagram of military command and control System

drawback of influence diagrams model is not considering that when commanders make the decision according to the opponent's strategy, opponents also act according to commanders' beliefs. One problem of traditional artificial intelligence methods is this method cannot show the reaction against environment efficiently, the intelligence body should do the reason analysis based on others' action and the other agent's belief also depends on the original agent's action.

Situation assessment frame based on Bayesian game: Military field is a perfect platform for the game. Each party would like to make full use of his own resources to reach the goal of completely against. In the situation of incomplete information game, incomplete information game can be converted into to complete but imperfect game by Harsanyi transformation and then it is analyzed by using of the standard game analysis technology (Harsanyi, 2004). Participant's type is a complete description of personal characteristics. Participant's action space and payoff depend on their types. Bayesian Nash equilibrium is a type of interdependent strategic combination $\{a_i^*(\theta_i)\}_{i=1}^n$. Every player i maximize his expected utility function under the established his type θ_i and the other's strategy relaying on the type $a_{-i}^*(\theta_{-i})$. In other words, $\forall i$, $a_i \in A_i(\theta_i)$ satisfies:

$$a_i^*(\theta_i) \in \arg\max_{a_i} \sum p_i(\theta_{-i}|\theta_i) u_i(a_i, a_{-i}^*(\theta_{-i}); \theta_i, \theta_{-i})$$

Because of the complexity and interdependent relationship of the problem, situation assessment is studied from two aspects of influence diagram and the game theory. First, the influence diagram is used to establish model for the development situation which does not rely on its own and other participants' actions, such as the action rules, terrain, etc. Payoff functions for Bayesian game under different situation are given. Estimate of the other's decisions are actually solving a Bayesian game. Models are developed for several states in objective reality and these states are packaged in the type combination of Bayesian game. Each model is represented as an influence diagram, including smart goals, possible actions, payoffs and deterministic results under each case. In addition to these variables, the influence diagram is collected with some other databases (as variables), such as terrain data repository, tactical rule base, etc. When the intelligent agent tries to make decisions based on other intelligent agents' actions, the influence diagram model is difficult to describe the causal relationship between different agents' decisions. For each graph model, through the comprehensive decision-making D_i, the utility U_i is calculated and an extended Bayesian game model is given for the whole decision-making problem. Solve the Bayesian game and get decision variables in the form the Bayesian Nash equilibrium solution.

From the above analysis, it can be found that the traditional artificial intelligence technology is powerless in decision making when the player makes his decision according to the other players' actions (Brynielsson and Arnborg, 2004). But the game theory has obvious advantages in describing the uncertainty problem.

RESULTS AND DISCUSSION

GECCO (Brynielsson and Wallenius, 2001) is used as the simulation platform in this study. Describe the state and game rule of local battlefield in this simulation scene and calculate the payoff function through influence diagram. Take two troops for example, given that A has two teams: A1 and A2, B has only one team. In this case, the decision of A2 was ignored, but its gain and loss are considered in the decision of both A1 and B. If A1 take the chance to occupy the base of B when B attacks A2, then B will lose a lot since its base is taken by A1. If A1 state calm when B attack A2, then A2 will fail well A1 has no loss. If A1 attack when B stake calm, A1 will lose a lot since its weak power. If neither A or B attack, they both win nothing.

The analysis shows that party A has two alternative strategies, offensive or attack. Party B also has two choices: not offensive or attack A2. In assumptions, A1 want to attack B and the premise is the fuel oil is enough. Party B don't know the specific information about A1's fuel, so party B assumes that $\alpha \in [0, 1]$ reflect A1's enough fuel in advance. Party B knows A1 has two possibilities, the plenty of oil and the lack of oil. But B doesn't know the precise information. Party B knows A1's strategies under different possible. For A1, party B also has two possibilities, knowing and not knowing. They have incomplete information about the other. The form of extension and Bayesian Nash equilibrium solution are analyzed as shown in Fig. 2 and 3. Abscissa is α in Fig. 3, the above curve is q, the probability of no attack from party B and the below curve is s which is the probability of no attack from party A1.

Each player only knows probabilities of other participants' types and don't know the real type, so it is impossible to know exactly which strategies other participants will actually choose. However, he can correctly predict how the other players' choices are related to their type. So, the decision goal of every player is maximizing his own expected utility based on his own and the others' types. Bayesian Nash equilibrium is a strategy combination relying on types: based on the probability distribution of others' types and his own types, every player's expected utility is maximized, which means no one has the motive of selecting other strategies.

When party A1's fuel is shortage, he will choose in the case of party B choose not to attack because that he clearly knows its own reality, corresponds to the D branch of the right branch in Fig. 2, rather than on the F branch. S represents the probability of no attack from A1, S represents the probability of no attack from B. From the analysis of above, it is known that equilibrium condition is that the player's utility should be the same when choosing different strategies. For party B, there is no difference on attacking (F) or not attacking (D). So, there is $s\times0+(1-s)\times\alpha = s\times1+(1-s)(-3\alpha)$. And from it $s = 4\alpha/(1+4\alpha)$ can be got. For party A, there is no difference on attacking (F) or not attacking (D). So, there is $q\times0+(1-q)\times(-1) = q(-\alpha)+(1-q)\times3\alpha$. From it $q = (1+3\alpha)/(1+4\alpha)$ can be got.

By Harsanyi's incomplete information static game theory, assuming that the key factors influencing the decision of both parties is fuel factor, it can be found that the strategy choose depends on the information of fuel situation of both sides under the premise of meet the requirements of individual rationality. When $\alpha = 0.5$ which means party B doesn't know any information, the possibility of no attacking from B is $q(0.5) = 5/6$ and the possibility of no attacking from A is $s(0.5) = 2/3$.

When $\alpha = 0$, there are $s = 0$ and $q = 1$. It means that party B chooses not to attack when he knows that A1 has no fuel and A1 will chooses to attack. This result is the same with the solution of static Nash equilibrium. At the beginning, party B is in the upper right corner of the screenshot, A1 and A2 are in the position of the lower left corner and the lower right corner respectively. The entire battlefield evolution is shown in Fig. 4a-c.

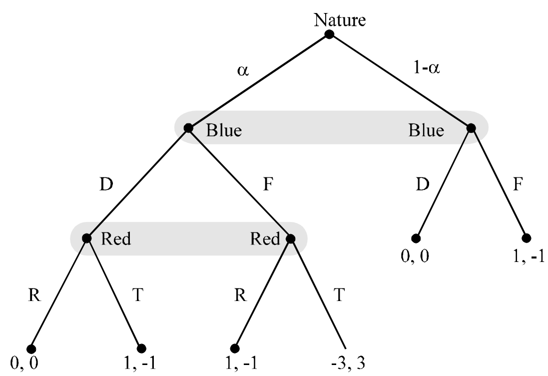

Fig. 2: The game tree of party A (red) and party B (blue) in local battlefield. The α represents the possibility of A1 owning enough fuel. F or T means fighting and D or R means no-fighting

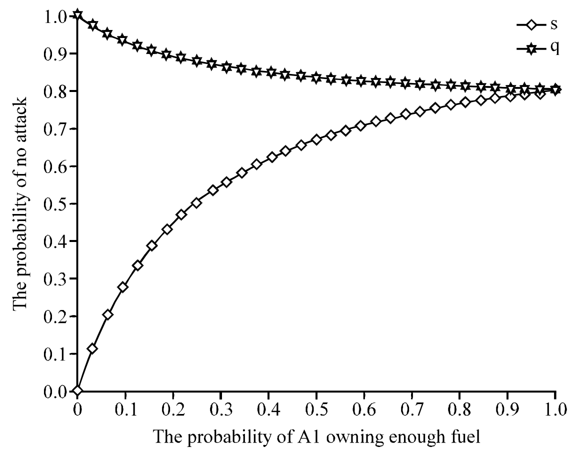

Fig. 3: The solution of Bayesian Nash Equilibrium: the upper blue curve (S) represents the Party B's probability of no attacking and the below red curve (S) represents the Party A1's probability of no attacking

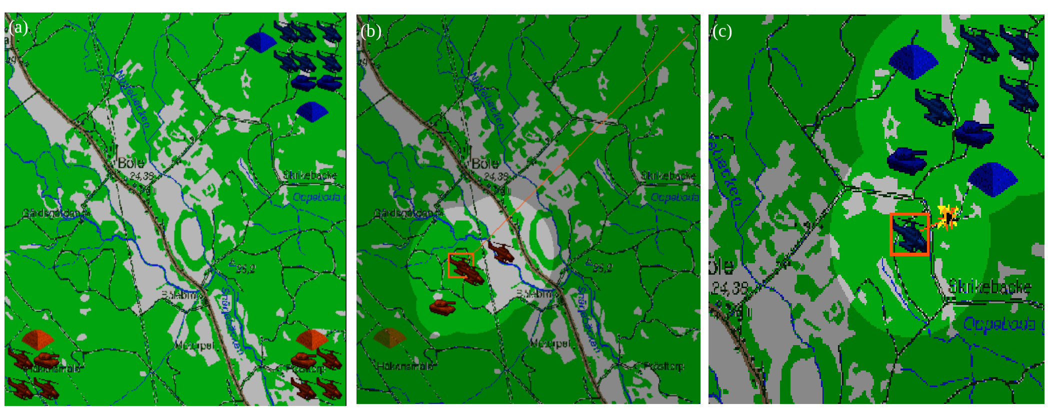

Fig. 4(a-c): The evolution of battlefield situation in the case: Party B (blue) knows Part A1 (red) lacks of fuel, Party B doesn't act, but Part A1 choose to attack Party B. (a) The initial situation strength distribution, (b) Party A1 is moving and (c) Party B wipes out Party A1

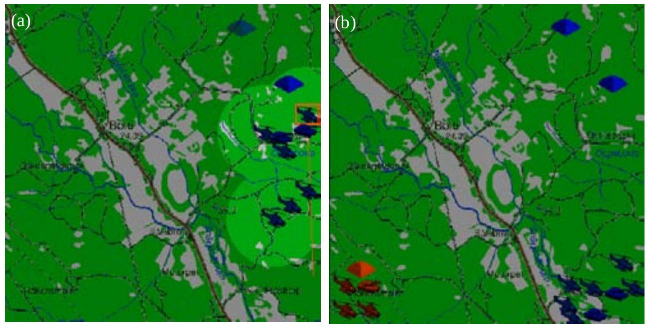

Fig. 5(a-b): The evolution of battlefield situation in the case: Party B (blue) knows Part A1 (red) own enough fuel, Party A1 attacks Party B and Party B attacks A2. (a) Party B (blue) Attack Party A2 at the and lower right corner and (b) Party B (blue) wipes out Party A2 at the lower right corner

When $\alpha = 1$, there is $s = q = 0.8$. It means that each party's possibility of no attacking is 0.75 when B confirms that A1 has plenty of fuel. If A1 attacks, the advance of B attacking A2 is shown in Fig. 5a and b. And A1 is in the left bottom.

CONCLUSIONS

In this study, the situation assessment is regarded as various individual interaction, rules, culture and military background more general and active process in dynamic battlefield environment. On the basis of analysis of alternatives, the Bayesian game theory is introduced to study the subjective thinking process of decision makers in situation assessment. The deduction is completed by using of the GECCO simulation platform. Finding the optimal decisions and analysis of the decision-making problem essentially understand game rules. Although the model can't make decision makers complete decision automatically at any time, it is indubitable to develop decision aid tools on the basis of game. The game theory and other methods must be combined and parallel developed at the same time, to ensure equilibrium results and the actual decision-making process is the same.

ACKNOWLEDGMENTS

This study was financed by the Central Universities Basic Research Funds Special Projects of Sichuan University (skq201119) and the China National Natural Science Foundation (70571055).

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