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An integrated approach based on game theory and geographical information systems to solve decision problems

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ABSTRACT

In this study, a military decision problem is handled by an integrated approach based on game theory and geographical information systems (GIS). The problem can be defined as: finding layout plan for troops who want to maximize probability of identifying enemies using particular routes to penetrate border line. The problem has been transformed to two-person zero-sum game by some assumptions and solved in four interconnected stages. First, suitable spots in the terrain for monitoring the enemies were identified. Then, visibility percentages of each of the spots were calculated by using GIS for the routes used by enemies to pass the border line. Next, by assuming the calculated visibility ratios as the probability of identifying the enemy, a two-person zero-sum payoff matrix was formed. Finally, linear mathematical model established to obtain optimal strategies with their probabilities. There are many techniques in literature to solve military decision problems but we believe that this study, by holding the peculiarity of the first study in which game theory and GIS are used together, will make a significant contribution to literature and future studies.

1. Introduction

Nowadays, there have been great improvements in the fields of science and technology. Using all kinds of technological innovations and scientific methods provides advantages to rival forces in battle field. In this scope, game theory and geographic information systems (GIS) are two of the frequently used scientific methods to solve military decision problems.

Game theory is the study of mathematical models of conflict and cooperation between intelligent rational decision-makers. Game theory is a discipline that has aroused much interest because of its novel mathematical properties and its successful applications to social, economic and political problems [1]. It is also becoming a part of the techniques used to solve military decision problems.

The world of constantly self-renewing and evolving technology offers new solution methods to military decision problems every passing day. Because of some unique properties, GIS has potential to become one of the most important weapons for military commanders [2]. GIS are systems designed to input, store, edit, retrieve, analyze, and output geographic data and information. Like all systems, GIS are composed of an orchestrated set of parts that allow it to perform its many interrelated tasks [3]. Nowadays, GIS which presents spatial applications has been used to solve military decision problems.

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The problem which we are trying to solve in this study is finding the settling plan of the troops who want to maximize the probability of identifying enemies using particular routes to penetrate the border line. Since the gains and losses of the enemies and soldiers originate from each other, the problem is to be considered as a two-person zero-sum game. The problem has been solved in four integrated stages. In the first stage, the spots in the terrain for monitoring the mission of the soldiers and possible distributions of soldiers to these points have been identified. Then, for each spot, visibility percentages of some specific routes which are possibly used by enemies to penetrate the border line have been calculated by using GIS. In the last stage, linear programming model has been established to obtain optimal courses of actions.

Traditional military problem solution techniques are mostly based on terrain analysis, evaluation of intelligence reports and utilization of some scientific methodologies. In this study, different from the applications in literature GIS and game theory are used together to solve a military decision problem. There are some studies in literature which use game theory or GIS independently to solve a military decision problem but this study has a characteristic of the first study in which game theory and GIS are used together. We have not also come across the idea to transform visibility percentages to payoff matrix in literature. Thus, it is expected to contribute to the literature and to promote studies in the field of other disciplines.

2. Literature review

Game theory is the theory of independent and interdependent decision making. It is concerned with decision making in organizations where the outcome depends on the decisions of two or more autonomous players, one of which may be nature itself, and where no single decision maker has full control over the outcomes. Obviously, games like chess and bridge fall within the ambit of game theory, but so do many other social situations which are not commonly regarded as games in the everyday sense of the word [1,4].

Game theory in the modern era was ushered in with the publication in 1913, by the German mathematician Ernst Zermelo, of *Uber eineAnwendung der Mengenlehre auf die Theorie des Schachspiels*, in which he proved that every competitive two-person game possesses a best strategy for both players, provided both players have complete information about each other's intentions and preferences. In 1921, the eminent French academician Emile Borel began publishing on gaming strategies, building on the work of Zermelo and others. He published five papers on this subject, including the first modern formulation of a mixed-strategy game [4].

Borel attempted, but failed, to prove the minimax theorem. The minimax theorem was proved for the general case in December 1926, by the Hungarian mathematician, John Von Neumann. Although Borel gave a clear statement of an important class of game theoretic problems and introduced the concepts of pure and mixed strategies, Von Neumann points out that he did not obtain one crucial result -the minimax theorem- without which no theory of games can be said to exist. In fact, Borel conjectured that the minimax theorem is false in general, although he proved it to be true in certain special cases. Von Neumann proved it to be true under general conditions, and in addition he created the conceptually rich theory of games with more than two players [5].

A milestone in the history of game theory is the work of Von Neumann on zero-sum games, in which he proved the famous minimax theorem for zero-sum games. This article was the basis for the book, *Theory of Games and Economic Behavior* by John Von Neumann and Oscar Morgenstern, by many regarded as the starting point of game theory. In this book the authors extended von Neumann's work on zero-sum games and laid the groundwork for the study of cooperative games [6].

In 1951, John F. Nash succeeded in generalizing the minimax theorem by providing that every competitive game processes at least one equilibrium point in both mixed and pure strategies. In the process, he gave his name to the equilibrium points that represent these solutions and with various refinements, it remains the most widely used game theoretic concept to this day [4].

One of the most important examples of the game theory use in military decision problems is the study of *Military Decision and Game Theory* published in the *Journal of the Operations Research Society of America* by O.G. Haywood [7]. This paper analyses two battle decisions of World War II, and develops the analogy between existing military doctrine and the 'theory of games' proposed by von Neumann. These two independent choices were the actual decisions which led to the conflict known in history as the Battle of the Bismarck Sea and The Avranches Gap Situation.

The articles written by L. D. Berkovitz and Melvin Dresher, applied mathematicians at the Research and Development (RAND) Corporation, were led to game theory applications in the field of military decision problems [8,9]. They worked on the problem in tactical air war concerned with the allocation at each strike of tactical forces among such competing air tasks as counter-air, air defense, and support of ground operations.

Cantwell suggested that the concept of two-person zero-sum game theory could improve military decision-making and developed this conclusion by conducting a historical analysis of the Tannenberg Campaign of 1914 utilizing game theory [10].

The 2007 article written by Dr. Hank Brightman, an associate Criminal Justice professor at Saint Peter's College and a USN Information Warfare Officer at the US Naval War College's War Gaming Department, posits that game theory suggests that US and Coalition forces stationed in Iraq will suffer an increasing rate of casualties the longer they remain in Iraq [11].

Another study example of the war in Iraq is Peter Devine's [12]. He illustrates one such alternative application by examining how economic models based on game theory and guided by so-called "Just War Principles" could help guide military policy intended to reduce civilian casualties in a counter insurgency.