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Research Article

OPERATIONS RESEARCH: APPLICATIONS TO MILITARY

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A R T I C L E I N F O

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A B S T R A C T

In World War II Operations Research was first used to effectively help high level decision makers to critically analyze various alternatives which could be fruitfully used to support planning for strategic ground, air, and maritime operations. Such an analysis made by Operations Analysts and Operations Researchers gave the military a carefully researched and focused data and also an analyses that provided not only answers to various questions from the senior commanders but also helped to provide them with insights that would allow them to make more comprehensive and informed plans and decisions.

After the Second World War, the various approaches and techniques used in Operations Research expanded and improved considerably, more so due to the advent of advanced computing techniques. Today, the principles and techniques of Operations Research are being widely used in government, business and industry. Every military across the world continues to use Operations Research from the point of view of improving its Operations Management in various strategies that are deployed.

In this paper, the Application of Operational Research in Military Strategies using Game Theory in various international wars has been discussed. These military strategies were used in the battles fought during World War II between the United States of America and Japan. An analysis has also been made regarding the military strategies used in the Battle of Bismarck Sea which was fought between General Kenney and Admiral Imamura where the strategy used was the zero-sum method of Game Theory. An analysis has also been made of the strategies that were used in The Game of Chickens and The Prisoner's Dilemma. These were applied in the Cuban missiles crisis which took place during The Cold War period, between the United Stated of America and The Soviets.

INTRODUCTION

This paper deals with the Application of Operational Research in Military Strategies using Game Theory in various international wars. These military strategies were used in the battles fought in the World War II between The United States of America and Japan. An analysis has been made regarding the military strategies used in the Battle of Bismarck Sea which was fought between General Kenney and Admiral Imamura by using the zero-sum game theory. An in-depth analysis of the scope of the future work of Operations Research has been done by studying The Battle of Bismarck Sea. The strategies that were used in The Game of Chickens and The Prisoner's Dilemma that in the Cuban missiles crisis which took place during The Cold War between The United Stated of America and The Soviets has been discussed as well. William Owen is a retired U.S. Army officer. He was an operational analyst.

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He employed the methods of Operations Research methods and models while in the U.S. Army and at the U.S. Joint Chiefs of Staff. He critically observed two primary areas where Operations Research techniques can be applied to assist decision makers. They were: one, operational testing of weapons and equipment and two, the modelling force-on-force military conflicts. In the first area, he used *statistics, test design techniques, and detailed analysis* when he provided operational assessments of army weapons and equipment such as the M1 tank, the M2/3 Bradley Fighting Vehicles and the Global Positioning System. In the second area, he created, used and *analyzed conflict models* to support operational decision makers.

His analyses using Operations Research were used by senior decision makers at the U.S. Joint Chiefs of Staff when preparing the strategic and operational plans for the first Gulf War. He also used conflict modeling for strategic movement and logistical planning for future conflicts.Basically, Operations Research (OR) started just before World War II in Britain. Teams of scientists were established in order to study the strategic and tactical problems involved in military operations. The primary objective was to find the most effective utilization of limited military resources by the use of Operational and Quantitative Techniques. In 1954, O.G Haywood used the Game Theory to analyse decisions made in the Battle of Bismarck Sea, a battle fought during the World War II. Haywood analysed the Battle of the Bismarck Sea by using a two-person zero-sum game. This paper also discusses the fundamental concepts of the two-person zero-sum game and some Nash Equilibrium dominance ideas as well as the strategies applied to the Battle of the Bismarck Sea based on the actual military operation.

In 2015, Nanjiang Liu from St. Lawrence University wrote a research paper on the zero-sum game theory in which a scope of future work has been analysed by us in this paper.The research on Cold war crisis has been done by using a number of sources that includes majorly the work done by Steven J. Brams. Techniques used to analyse the Cuban Crisis I Cold war include The Chicken Game and Prisoner's Dilemma.

Literature Review

Kulve H, Smit W in their research paper titled *Civilian-military co-operation strategies in developing new technologies* have dealt with the dual use technology where that have advocated as the solution for the twin problem of maintaining a high tech defense technology base and improving economic competitiveness.

Biddle Sin his paper Military Power Explaining victory and defeat in modern battlehas presented the following cases namely Operation MICHAEL, the German offensive in the Second Battle of the Somme.

Woodward R in his paper titled *Military Geographies* speaks about about how local space, place, environment and landscape are shaped by military presence, and about how wider geographies are touched by militarism.

Burk J in his paper titled *Military Culture* speaks about the historical and comparative exploration, primarily of Western military culture, covering three themes: (1) the elements of military culture, (2) the sources of continuity and change in military culture, and (3) the relation between military culture and the larger society.

Game Theory

The Game Theory is the science of strategic reasoning for dealing with competition where the outcome of a participant's choice of action is based critically on the actions of other participants. Game Theory is usually applied to psychology, economics and political science. This paper focuses on the application of Game Theory in the military area and wars, a field that is apparently not so very well known by people.

We are majorly going to discuss the two-person zero sum game, in which one player's gain is equivalent to another player's loss, causing a net sum of zero. To analyse a two-person zero sum game, we introduce a simple mathematical description, the Strategic Form.The strategic form of a two-person zero-sum game is given by a triplet (X, Y, A), where:

1. X is a nonempty set, the set of strategies of Player I
2. Y is a nonempty set, the set of strategies of Player II
3. A is a real-valued function defined on X × Y. (Thus, A(x, y) is a real number for every $x \in X$ and every $y \in Y$.)

This definition could be addressed as follows. Player I choses $x \in X$ and Player II choses $y \in Y$ concurrently, and each player is oblivious of the choice of the other. The amount Player I could win from Player II is A (x, y). If A <0, Player II loses this amount. Therefore, A(x, y) provides the winnings of Player I and the losses of Player II.

The minimax value and the maximin value are frequently used terminologies in two-personzero-sum game. As they will be used in later section,

We give the definitions as follows.

The maximin value of a player is the largest value that the player can be sure to get withoutknowing the actions of the other player.

The minimax value of a player is the smallest value that the other players can force the player toreceive, without knowing his actions.

Under many situations we may obtain the same maximin and minimax values. When suchencounter comes into existence, this outcome is called as an equilibrium outcome and this is calledas a saddle point.

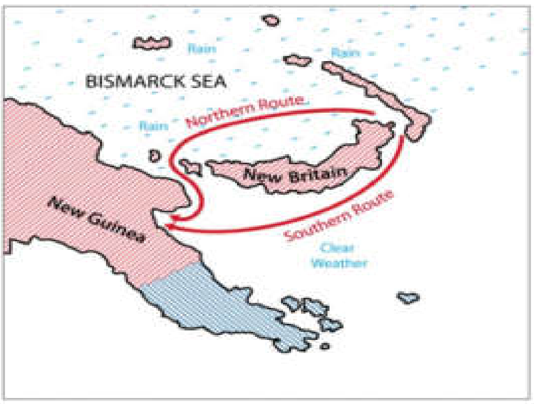
Therefore, when the maximin and minimax are said to be in equilibrium, the outcome associated with them is called a saddle point.

Battle of Bismark Sea

Background

The Battle of Bismarck Sea was a battle fought in February 1943 in Southeast Asia, amid the World War II, between the Japanese Navy and U.S. Air Force. Admiral Imamura was the commander of Japanese navy and General Kenney was the commander of the U.S. aviation-based armed force. The Japanese Admiral was ordered to deliver reinforcements for Japanese soldiers fighting in Papua New Guinea.

The Japanese reinforcements could be sent in two ways, either by the Northern Route, through the Bismarck Sea, or by the Southern Route, through the Solomon Sea. By either route, it would have taken 3 days to reach the New Guinea coast at that time.



The area which is shaded red (figure above) was under the control of the Japanese while the area which is shaded blue was under the U.S. control.

General Kenney knew all the routes that were available for the Japanese in order to send reinforcements. If the U.S. General correctly anticipated the Japanese's move with regard to supply of reinforcements and hence sent his planes towards that route, the U.S. forces would have then had more days for bombing. In case, however if the U.S. General had predicted the wrong route, he then would have had to redirect the planes and therefore, would have lost one day of bombing.

We assume the "payoff" in this game to be the number of days of bombing. If it is taken as positive for the U.S forces then it would be negative for the Japanese. It would be noted that the number of days are the same for both, that is, for the US and the Japanese, except that it is positive for one and negative for another. Therefore, this is called as a Two-person Zero Sum Game.

Hence, a two-person zero-sum game is a situation where one person's gains are balanced by another person's losses. Thus we get a total sum of zero when we add the gains and the losses.

Scrutinising the Battle of Bismarck Sea

According to the U.S. Military's Doctrine of Decision, the U.S. commander makes decision either based on enemy capabilities or on enemy intentions. In this Battle, General Kenney's decisions are based on enemy capabilities, what the Japanese Admiral could do to oppose him.

He used a five step process, called Estimate of the situation to make decision:

The Mission

As ordered by the Supreme Commander General MacArthur, the mission for General Kenney was to cut off and expose maximum annihilation of the Japanese reinforcements convoy.

Situation and course of action

There was one limiting factor as pointed out by General Kenney's staff. Bad weather was predicted in the north which would possibly be accompanied by poor visibility. Such a situiation would directly affect the bombing days for U.S. and thereby reduce it to 2 days. While the weather in south was predicted to be normal which thereby ensured 3 days of bombing for U.S. However, for the Japanese troops, it would take three days for them to reach their final destination

Analysis of the Opposing course of action.

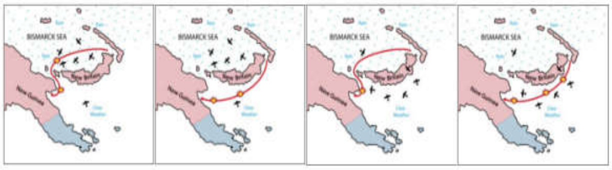
Each commander would have two alternative routes, thus resulting in four possible clashes that could potentially arise.

In the first scenario, General Kenney would concentrate most of his aircrafts on the Northern route, and the Japanese Navy would also take the Northern route. Due to bad weather conditions and poor visibility, there would be only two days of bombing by U.S. airforce.

In the second scenario, General Kenney would concentrate most of his aircraft along the Northern route. But this time, Japanese Navy would take the Southern route. Since most of its reconnaissance would be on the northern route, the US would therefore miss the first day of bombing the Japanese.

In the third case, the U.S. Air Force would be located along the Southern route, and the Japanese Navy would take the Northern route. Due to the poor visibility and the low-level of reconnaissance, the Japanese would be missed for two days in terms of bombing, thereby allowing the US only one day of bombing.

In the fourth case, both the U.S. Air Force and the Japanese Navy would take the Southern route. Due to the good visibility and the majority of air force being available, General Kenney could now have three days of bombing.



(a) Scenario 1 (b) Scenario 2 (c) Scenario 3 (d) Scenario 4

Comparision of Available courses of action

General Kenney sought a conflict with maximum days of bombing, while Japanese Adminral wanted minimum exposure to bombing. But neither of them could determine the result of the battle based on their own decisions, thus a matrix of all possible conflicts is formed. The rows listed Kenney's strategies, and the columns listed the Japanese strategies. The number at each intersection represents the number of days of bombing.

		Japanese strategies	
		#1-Northern route	#2-Southern route
Kenney strategies	#1-Northern route	2 days	2 days
	#2-Southern route	1 day	3 days

In Game Theory, we add an extra row and column.

As for General Kenney, he wanted his outcome to be greater than or equal to minimum in any row so that he had as many days of bombing as possible. Therefore, we put minimum values of each row in the extra column. We can clearly see that if U.S. took the northern route, they would get 2 days of bombing and if they took the southern route, they would have 1 day for bombarding Japanese Navy (considering minimum values). Hence, they chose the Northern route where they would get the greatest promise of success. Thus, Kenney would select the maximum value from the column of minimums. This is called the Maximin and the value is 2 days. As for the Admiral, he wanted to minimize his exposure to bombing and so would choose the worst (maximum) situation in each column. Thus, the maximum values of each column will be put in the extra row. If he chose the northern route, he would be exposed to 2 days of bombing, while if he took the Southern route, he might be exposed to 3 days of bombing. Since he required minimum exposure to the bombs, he will select the minimum value from the column of maximums. This is known as Minimax and the value is 2days.

		Japanese strategies		Minimum of row
		#1	#2	
Kenney strategies	#1	2 days	2 days	2 days (maximin)
	#2	1 day	3 days	1 day
Maximum of column		2 days (minimax)	3 days	

Strategic form representation of the Battle of Biismarck Sea.

The Decision

Based on our analysis of the game theory, both Japanese Admiral and General Kenney would choose the Northern

Route. Not surprisingly, the outcome we predicted was identical to the actual result of the battle. The identical result was not a co-incidence. In the game theory there is an outcome in which both the players yield the same outcome which is called as the "saddle point". There are two reasons why players in a zero- sum game should choose a strategy

ssociated with a saddle point

1. A player's security level will be maximized using a saddle point.
2. A player will keep the other player from keeping his security to the maximum level by using the saddle point concept

The concept of saddle point leads to the discussion of Nash Equilibrium in the Battle of Bismarck. When it comes to Nash Equilibrium we always want to find a strategy for players that neither player has an incentive to change strategy based on what the other player does.In the Battle of Bismarck Sea, neither General Kenney or Admiral had a dominant strategy. The payoff table shows that Kenney would have chosen the Northern route if i) he thought that the Admiral would chose the Northern route and ii) if the Admiral chose the Southern route. On the Admiral's side he would have chosen the Northern route if i) he thought Kenney would choose the Southern route, ii) he would be indifferent between choices if Kenney chose the Northern route. However we can use the concept of of ***"weak dominance"*** to find a possible equilibrium.

One way to acquire weak-dominance equilibrium is through deleting all the weakly dominated strategies of each player. In the Battle of Bismarck Sea, the choice of Admiral to go South is weakly dominated by choice of taking the Northern route, because his payoff of going North was never smaller than his payoff in going South.But there was no weakly dominated strategy for Kenney, hence we discuss the idea of iterated dominance equilibrium.An iterated-dominance equilibrium is a strategy profilele found by deleting a weakly dominated strategy from the strategy set of one of the players. Recalculating which remaining strategies are weakly dominated, deleting one of them, and continuing the process until only one strategy remains for each player.

Applied to the Battle of Bismarck Sea, Kenney believes the Admiral would take go North as it is weakly dominant. After taking one scenario out of consideration, Kenney has a strong dominant strategy : to take the Northern route as he would achieve payoffs strictly greater than the resuts in going South.Therefore, the strategy (North, North) was an iterated-dominance equilibrium, which was the actual outcome of the Battle.

War analysis

The crew of one of General Kenney's bombers spotted a large Japanese convoy heading towards New Guinea on March 1, 1943. Thus began the Battle of the Bismarck Sea. During the three days that followed, the crews of 162 Allied planes repeatedly attacked this convoy and its protective cover of land-based fighters. Total Army Air Forces personnel losses came to 13 while the Japanese lost approximately 12,700 officers and men.This clearly tells us General Kenney made the right decision by choosing the Northern Route and hence won the Battle.

Analysis of Scope

We may now consider modifying the order of play or the information structure in The Battle of the Bismarck Sea. If Kenney moved first, rather than simultaneously with Imamura, (North, North) would remain an equilibrium, but (North, South) would also become one. The payoffs would be the same for both equilibriums, but the outcomes would be different. If Imamura moved first, (North, North) would be the only equilibrium. The importance about a player moving first is that it gives the other player more information before he acts, *not the literal timing of the moves*.

If Kenney has cracked the Japanese code and knows Imamura's plan, then it does not matter that the two players move literally simultaneously; it is better modelled as a sequential game. Whether Imamura literally moves first or whether his code is cracked, Kenney's information set becomes either {Imamura moved North} or {Imamura moved South} after Imamura's decision, so Kenney's equilibrium strategy is specified as (North if Imamura moved North, South if Imamura moved South).

Application to Cold War

The Cold War, which started after World War II, was characterized by a state of political and military tension between primarily the United States and the Soviet Union. This broke the former alliance between two superpowers as they were strongly divided over economic and political ideologies.While these two nations never clashed directly on the battlefield throughout this time, their competition for nuclear supremacy resulted in the ever-present threat of an all-out nuclear war between the two nations and their allies.This quickly became a scenario in which neither nation could gain the upper hand through a nuclear war.The repercussions would be too devastating, as the opposing nation would be in possession of the same weapons and would be completely capable of issuing a counterattack via second strike. This doctrine is called as ***mutually assured destruction***. This quickly became a scenario in which neither nation could gain the upper hand through a nuclear bombardment; the repercussions would be too devastating, as the opposing nation would be in possession of the same weapons and would be completely capable of issuing a counterattack via second strike. ***Mutually assured destruction*** is in itself, a Nash equilibrium which means once armed, neither side has any incentive to initiate a conflict or to disarm. It is based on the theory of deterrence which holds that the threat of using strong weapons against the enemy which prevents the enemy's use of those same weapons.

Cuban Missiles Crisis

Cuban missiles crisis which was started by The Soviets because The Soviets installed missiles on Cuban soil, close enough to attack the United States. In chronological order, the important events were as under:

14^{th} October - US spy plane found the missiles bases being built in Cuba .
October 20^{th} and 21^{st} - US responds with a blockade coupled with the demand that The Soviets withdraw the missiles.
October 28^{th} - Soviets announce they would withdraw the missiles.

The goal of this research is to explain 2 questions

1. Why was there a build-up of a missile base and then a subsequent blockade
2. Why was there no conflict between the US and The Soviets?We will use the following to concepts of the

Game Theory to answer the above questions respectively:The Game of Chickens and The Prisoner's Dilemma.

The Game of Chickens

Why did the world observe the deployment of missiles and the subsequent blockade?

The answers were as follows

- The United States wanted to protect itself and hence wanted to invade Cuba.
- The U.S. wanted The Soviets (the 'enemy') to believe the U.S. will not hesitate to attack.
- Effectively, the Cuban Crisis was a psychological conflict. The winner would have political advantage in other fields of the Cold War

What is The Game of Chickens?

Consider that two cars driving towards each other. The first car that swerves loses the game.

The outcome of this game can be written in the following matrix form:

Player II:
Swerve Straight

Player I: Swerve Tie, Tie Lose, Win
Straight Win, Lose Crash, Crash

We now arbitrarily set numerical payoffs which theoretically conform to this situation. Here, the benefit of winning is 1, the cost of losing is -1, and the cost of crashing is -10.

		Player 2	
		Swerve	Straight
Player 1	Swerve	0 , 0	-1 , +1
	Straight	+1 , -1	-10 , -10

The two pure strategies to this game are (1) (Swerve, Straight) and (2) (Straight, Swerve). We consider these two strategies because, for all practical purposes, these two outcomes are most likely to happen

Application of the Game of Chickens to Cuban Missiles Crisis

In order to apply the Game of Chickens, we need to decrypt and decode the following things

a) the players (b) their actions (c) their payoffs

In Cold War, the players involved as well as their actions are

Player 1 – John F Kennedy (a) Do nothing (b) Respond with a blockade

Player 2 - Nikita Khrushchev (a) Keep deploying missiles (b) Retreat.

Payoffs

		USSR	
		Retreat	Deploy more missiles
USA	Do nothing	0 , 0	- 1 , +1
	Blockade	+ 1 , - 1	- 10, - 10

After understanding the matrix two questions arise

1. Why did the USA respond with a blockade? and
2. Why did the USSR retreat?

Reason is that because in the Game of Chickens it is important to show your enemy you will not swerve.

Hence, Kennedy knew he had to do something as he quoted in one of his interviews '…..the biggest danger is to **do nothing.'** Main idea behind the Chicken Game was brinkmanship, that is, to bring the situation to the edge of a disaster in order to achieve highest possible outcome.To understand this Chicken Game well let us see an in depth explanation of the pay off matrices

		Soviet Union	
		Withdrawal (W)	Maintenance (M)
United States	Blockade (B)	(3,3) Compromise	(2,4) Soviet victory, US defeat
	Air Strike (A)	(4,2) US victory, Soviet defeat	(1,1) Nuclear war

Key: (x,y) = (rank of the US, rank of Soviet Union); 4 = best; 3 = next best; 2 = next worst; 1 = worst.

Analysis of the above figure scenario matrix

- The best strategy for the Soviet would be BM(2,4) and for the US would be AW(4,2).
- However, each player risks that the other player will choose the best strategy AM(1,1) or Nuclear War
- Since each player's choice depends on the other player's choice, it gives an incentive to one player not to cooperate hoping the other player to concede and the given player canthen make the best choice
- The strategy BW(3,3) is considered unstable as both the players have an option to choose a strategy that gives out the best outcome
- Hence, we note that this model is inadequate as it shows only two options (both sidesconsidered more than two alternatives) and it assumes that the players choose theiractions simultaneously

		Soviet Union	
		Withdrawal (W)	Maintenance (M)
United States	Blockade (B)	(3,3) Compromise	(1,4) Soviet victory, U.S. capitulation
	Air Strike (A)	(2,2) "Dishonorable" U.S. action, Soviets thwarted	(4,1) "Honorable" U.S. action, Soviets thwarted

Key: (x,y) = (rank of the U.S., rank of Soviet Union); 4 = best; 3 = next best; 2 = next worst; 1 = worst.

Scenario analysis

1. The compromise option BW(3,3) remains the same.
2. The option BM(1,4) is when the US blockades and the Soviet ignores the warning and hence it is a victory for the Soviets. The BM option proves to be the best option for the Soviets and the worst for the Us
3. The option AW(2,2) is when the US lays an air attack on the missiles that the Soviets were
4. Withdrawing proving it to be 'dishonorable' on the US side, that is, second to the worst outcome, which thwarts the Soviets, that is, the second worst outcome The option AM(4,1) is when the US lays an air attack on the missiles, that is, the bestoutcome for the US and the missiles getting destroyed, that is, worst outcome for the Soviets.
5. The above two models gave us two Nash equilibriums based on strategy and preference.Kennedy's strategy was now to put up a blockade forcing Khrushchev to retreat, that is, AW(4,1).This follows the "Game of Chickens".

The Prisoner's Dilemma

In order to answer the second question in the above case, that is, 'why did the Soviets retreat'; we now use Prisoner's Dilemma to understand why we did not observe a conflict.

Briefly, the Prisoner's Dilemma may be stated as follows

1. two prisoners locked in separate rooms.
2. Dominant strategy for each of them is to betray. The resulting outcome is worse for both of them

		Prisoner 2	
		stay silent	betray
Prisoner 1	stay silent	0 , 0	- 5 , 5
	betray	5 , - 5	- 3 , - 3

The unique equilibrium of this game is (betray, betray); this is quite a "bad" equilibrium for the two prisoners.

We apply that game to the potential conflict between two countries, the US and the Soviets:

		USSR	
		Don't attack	Attack
USA	Don't attack	0 , 0	- 5 , 5
	Attack	5 , - 5	- 3 , - 3

The unique equilibrium of this game is (attack, attack) which is quite a "bad" equilibrium for both countries (and of course, to the rest of the world!). Let us now understand with respect to the Prisoner's Dilemma.

1. Tomorrow is important!
2. If the Soviets attack today, then the USA will retaliate tomorrow.
3. Modify the objectives, that is, each player cares about the stream of pay offs over allthe periods

Example 1: Suppose USA and USSR restrain from attacking in each period. If so, then, what are their pay offs?

a. Today: 0
b. Tomorrow: 0
c. The day-after-tomorrow: 0
d. etc.

Example 2 : Suppose USSR considers attacking today but knows that it will cause retaliation Tomorrow. What are pay-offs?

a. Today: 5
b. Tomorrow: -3
c. The day-after-tomorrow: -3
d. etc.

If we care enough about tomorrow, it is possible to make (don't attack, don't attack) an equilibrium of the game. The "psychological" conflict in 1962 did not turn into an open war.

Conclusion And Future Work

The application of Game Theory in wars is very unique and has proved to be helpful in several cases. It is based not only on mathematics but also has a scientific logic behind it. It ensures detailed analysis of all the options available before finally arriving at a conclusion. Strategic formation of matrix and use of two-person zero-sum game helped General Kenney tocome to a conclusion of taking the northern route, which lead to their victory and heavylosses being suffered by the Japenese.

Actually, the use of Game Theory in today's military decision making process is very similar towhat we had seen in the Cold War. As military decisions should be made depending on both thestrength of a nation's army and its political power, the explicite use of Game Theory inmilitary decision-making process has been made in order to demonstrate understanding of problemsin international relations and thus enlightening military officer on decision-making.

Since Game Theory plays an important role in providing both mathematical solutions and politicalinspiration, studying it could shed light on future political and military movements.
A possible future work direction is to look at a variation of the two-person zero-sum game,that is, the two-person zero-sum game without a saddle point. In the discussions above, we only talked about the two-person zero-sum game with a saddle point.

However, there exists such situations where no saddle point can be found. Consider the Battle of Avranches-Gap,which occurred in August 1944 right after the invasion of Normandy. This battle can beregarded as a two-person zero-sum game ***without*** a saddle point as there does not exist anequilibrium outcome. In other words, it must be the case that either one player can dobetter if one can deduce the enemy's intention. This variation of the two-person zero-gameis worth further exploration as it not only has been used in previous battles but it may alsobenefits future military decision making process.

Regarding the Cold War analysis, the entire Cuban Cris is explained with the help of differrent techniques prevailing in the Game theory. We see that using the Game Theory to analyse the strategies has proved to be beneficial as in the case of General Kennney, wh made the right decision and took the northern route and won the battle.Using the Chcken's Game and Prisoner's Dilemma, the USA created a blockade and the USSR retreated its missiles which saved the world from another nuclear war.

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