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METEOROLOGY—VITAL ELEMENT OF NAVAL PLANNING AND OPERATIONS

A lecture delivered
at the Naval War College
6 January 1961

by

Captain William J. Kotsch, USN

INTRODUCTION

For centuries, weather and climate have been a factor in the prosecution of wars, but in the last fifteen years their importance has increased markedly. In Naval strategic, tactical, and logistical planning and operations, the meteorological factor can almost never be ignored and may sometimes be decisive.

As the result of great technical strides and scientific achievements, the Navy—as well as the other Services—has greatly increased its sensitivity to the meteorological environment. And along with this, the advent of the nuclear-missile-space era has precipitated a seeming inconsistency of no small magnitude. Today, from the standpoint of nuclear, chemical, or biological warfare, a nation surrounded by its allies is much more vulnerable than a nation surrounded by its enemies! And this adds greatly to the complexity of the tasks confronting the modern decision-makers.

The United States is surrounded by friendly nations. Consequently, the Soviet Union could unleash large-scale nuclear devastation against the United States heartland with little concern for lethal contamination of South America, the Caribbean area, Mexico, or Canada, by radioactive fallout. And the same applies to the employment of chemical or biological techniques.

The Soviet Union, on the other hand, is largely surrounded by neutral or uncommitted nations, by United States allies or countries friendly to the United States, and by countries which have been coerced into joining the "bloc of tyranny" (and whose peoples are largely anti-Soviet). And herein lies one of today's many problems.

Under a variety of meteorological conditions, a large-scale nuclear retaliatory attack against the heartland of the USSR would also constitute a concomitant attack against United States allies, neutral nations, and anti-Soviet citizenry geographically situated in the "rimland" of the Soviet Union and beyond. The magnitude of the concomitant attack—the fallout of radioactive debris—would depend in large measure upon weather conditions. And in particular, upon wind patterns extending from the lower levels to extremely high levels in the atmosphere.

Which of these countries would be subjected to radioactive contamination? To what degree? When? The answers to these and many related questions must be provided to Naval planners and operational commanders. For many reasons, competent and timely meteorological information is no longer "desirable." It has become *mandatory*.

WEATHER SERVICE, A TWO-SIDED COIN

Naval commanders at sea have always taken the weather factor into account whenever possible. Before the days of steam, commanders were constantly forced to alter position in order to take advantage of the wind. They constantly attempted to "gain the weather gauge"—to get to windward of the enemy so that the enemy could be approached when desired. And if a strategic retreat was a likely course of action, the shrewd Naval commander maneuvered his force to leeward so that he could turn and retreat without having to penetrate the enemy's line.

Before the birth of military weather forecasting in the 1850's, Naval commanders were limited to an anticipation of future weather conditions on a very general basis. Constant operational readjustments to the specific meteorological situation were required as that situation unfolded. But since the Crimean War (1854-56), the meteorological factor has never again been viewed with palsied fatalism.

Today, in addition to competent leadership, a highly mobile, flexible, efficient, and punch-packing Navy demands a specialized meteorological organization to meet specialized requirements extending from the depths of the hydrosphere to the great heights of the stratosphere and beyond. This is why the navies of almost all major countries have their own organization of weather scientists, forecasters, and technicians to provide, if at all possible, the requisite information, data, and studies to meet the diverse requirements of Naval planning and operations. And in this complex era, this is far from a simple task.

Some Scientific Facts of Life. In many instances, the Naval meteorologist is not able to effectuate *exactly* the data and information which the planners and operators state as requirements. The fault lies primarily with the tenuous nature of the earth's envelope of air and the difficulties encountered in observing, measuring, and describing the weather and oceanographic parameters inherent in Naval problems.

Naval meteorologists—like other meteorologists—are unable to observe weather and oceanographic elements with 100% accuracy. Limitations on their ability to do this stem primarily from restrictions inherent in sensing equipment and the "representativeness" of the particular observation as it relates to a specific plan or operation. In other words, does the observation really define the requisite parameters? Also, how relevant is the observation to what *should* be observed?

In general, it can be stated that the capability of the Naval meteorologist to meet requirements for weather and oceanographic information is satisfactory for most purposes. Exceptions to this are those parameters lacking precise physical definition, such as "visibility."

Shortcomings similar to those inherent in the observation of certain weather elements are also encountered in the provision of climatological information for operational or planning purposes. And these shortcomings result primarily from the paucity—or complete lack—of data for remote land areas and the vast oceanic expanse. For, whenever the distribution of weather or oceanographic parameters must be extrapolated from data at a distant point, precision is drastically reduced.

With regard to the *future* state of the atmosphere or the hydrosphere, weather and oceanographic predictions possess all the uncertainties inherent in both the observational and climatological aspects, and in addition, a variety of other factors peculiar to the process of forecasting. Forecasts are derived either from the solution of an initial value problem in which the predicted element is defined in terms of its initial value or its time derivatives, or the values are determined from an extrapolation of a time series of the particular element. The basic difficulty stems from the fact that the atmosphere and the hydrosphere are media in which cause and effect are *always* multiple and complex relationships. These are the scientific facts of life, at this writing, and no solution appears imminent.

Current Fleet Requirements. Even though geographical, meteorological, and oceanographic considerations have always played a role in warfare at sea, it has been only within the last fifteen years or so that nature has subtly influenced and affected instrument and equipment design—particularly that of undersea warfare. The distribution of salinity, temperature, and pressure within the sea govern its sound-transmitting properties. And even the character of the bottom is an important factor. Consequently, oceanography (a responsibility of the Naval meteorologist) has become a vital factor in weapon systems studies, as well as in "routine" plans and operations.

The "environment" of undersea warfare varies both geographically and seasonally. And what is happening in the earth's atmosphere—the actual weather—strongly affects the temperature gradient in the hydrosphere which, in turn, determines acoustic paths. As a result, it is extremely unlikely that any one weapon system will ever be optimal under all circumstances. Obviously, then, advance knowledge of probable detection ranges by various techniques can significantly increase the efficiency of barrier, hunter-killer, and large-scale ASW operations.

This, of course, applies to the performance of radar equipment in the atmosphere, as well as to sonar equipment beneath the surface of the sea. For both radar and sonar are extremely sensitive to their environment in their effectiveness of operation. And the Naval meteorologist must be Johnny-on-the-spot with these predictions to assist the operational commander.

The numerous weather and oceanographic variables influence the different types of Naval operations in many ways. Consequently, in the planning or conduct of these operations, it is necessary to thoroughly consider all weather and oceanographic requirements, arrive at the best possible balance, and define the minimal requirements on an overall operational basis. This analysis is a difficult procedure, requiring judgment of the highest calibre. And in no type of operation is the analysis more difficult than in amphibious operations, which involve the effectual coordination of sea, air, and land forces.

Despite many predictions to the contrary subsequent to World War II, amphibious-type operations have again assumed prominence in the warfare-technique arsenal as the result of the birth of "limited war." And while amphibious craft are sensitive to wind speed, wave height and period, the vertical assault technique is highly sensitive to wind speed, gustiness, and turbulence. Thus, prior knowledge of these, and other, conditions is mandatory for the efficient conduct of these types of operation.

Carrier Task Force operations with high-speed, high-altitude jet aircraft; sustained operations at sea, including the underway refueling and replenishment of units; the complex procedures and decisions inherent in the selection, delivery, and escape techniques concerning special weapons; mercy missions and search and rescue operations; the prediction of intricate radioactive fallout patterns, for offensive and defensive purposes; optimum ship-routing operations (which save the Navy more than ten million dollars per annum); all demand a highly-specialized weather and oceanographic service.

The advent of missiles and their incorporation into the Navy arsenal have served to increase, rather than decrease, the stringent planning and operational requirements placed upon the Naval Weather Service. At the present time, there are missiles of all types and ranges, performing offensive, defensive, and special missions. Many of these streak at supersonic speeds to their target. But regardless of the type of missile, the nature of its guidance system, or its speed, as long as the missile is within the earth's atmosphere, its performance will be influenced by one or more of the many weather elements.

Missiles cannot correct for unexpected circumstances. Stratospheric clouds can blot out the stars. Radar beams can "bend" considerably. Most unusual changes in air density can—and do—occur. Stratospheric winds in excess of 350 knots are frequently encountered. This factor alone could result in a Mach-3 missile detonating 20 miles off-target. For, such a missile can be thrown off course in the last few minutes before homing, without sufficient time to correct for the deflection.

Only the true ballistic missile, because of its fantastic speed, will be relatively free of the weather elements during flight. But the effects during and subsequent to the warhead's detonation are still determined largely by weather conditions. Snow cover and cloud cover, humidity, vertical distribution of temperature, precipitation, and wind patterns will continue to determine the efficiency of the blast, thermal, and radiation effects, and the distribution of radioactive fallout.

Chemical and biological warfare techniques are perhaps the most weather-sensitive techniques of all, demanding a precise and accurate knowledge of existing, and especially of future, weather conditions.

Thus, current Fleet requirements for meteorological data and information are as numerous as they are diverse. And it is incumbent upon the Navy's weather organization to provide this vital information at all cost, subject only to scientific limitations.

Naval Weather Service Requirements. In order that the Naval Weather Service may provide the requisite data and forecasts to the best of its ability in meeting Fleet requirements, it is essential that the Fleet do its part.

During the initial stages of the planning process, the meteorological and oceanographic aspects and implications should be closely examined. A Naval meteorologist should be invited to act as a "consultant" to all new plans, programs, and operations at the earliest practicable stage, for the proper use of this type of data requires a finite recognition and assessment of the indeterminate character of the earth's envelope of air. The uncertainty factor is as important as knowledge of the weather and oceanographic elements, themselves. The meteorologist should be encouraged to carefully examine the flexible factors in order to determine the combination of operational factors which promises optimum chance of success.

Detailed briefing requirements should be clearly specified by Naval planners and operational commanders and data content and format requirements should be well-defined. As in any field of science, the degree of success is largely a function of accurate observations. Air, surface, and subsurface Naval units, therefore, should conscientiously make these observations in accordance with existing instructions. Equally important, timely reports of these observations should be made by Fleet units to the proper Navy weather activities. Such was the case during World War II. And Fleet units should forward complete weather and oceanographic records to designated activities for climatological, statistical, and research purposes, if the Naval Weather Service is to provide the calibre of support which the Fleet of today requires. Thus, the provision of efficient weather and oceanographic service to the Fleet is, indeed, a two-sided coin.

METEOROLOGICAL IMPACT ON MODERN DECISION-MAKING

Even though mankind is now in a simultaneously wondrous and appalling scientific and technological era, human intelligence remains the most vital single entity. The human brain has not been replaced by the electron tube, nor is it likely to be for a long, long time. And the capacity for sound decision remains all-important.

Despite tremendous strides in the world's push-button technology, it is still man and his decision-making ability that really counts, not the button. And never before in the Naval and military history of mankind has the weather factor entered so forcefully into the decision-making process.

Earth satellites, rockets, missiles, manned aircraft, nuclear and CBR weaponry, and surface and subsurface ships are all weather-sensitive. It is only a matter of "degree of sensitivity." For, all operate within the earth's atmosphere, at least a part of the time.

Perhaps one of the most difficult decisions confronting today's Naval planner and operational commander is that of the optimum weapon system—to accomplish a particular mission, in a designated distant geographical area, at a specified time, with minimum risk to own and friendly forces or areas. For today, this must be accomplished under whatever weather and oceanographic conditions may envelop one's own forces and whatever conditions may cover target areas at the specified time. One thing is certain. Making such a decision without competent meteorological advice could easily be the prelude to failure—and perhaps disaster.

An unmanned vehicle of destruction with a radar guidance system should not be utilized if electrical storms are indicated or predicted in the troposphere or the ionosphere, for the vehicle will miss its target by a wide margin. A missile with infrared homing should not be used if it is forecast that the target is, or will be, obscured by multiple cloud layers, or even a single heavy cloud layer. For, the water droplets comprising the cloud masses absorb up to 75% of the target's emitted infrared in the critical wave-length bands. Under these conditions, it would be almost impossible to calculate in advance the point of impact.

Even the extremely sophisticated missiles containing autonavigation systems are not invulnerable to the effects of the weather. And the efficiency of an orbiting reconnaissance satellite is highly vulnerable to the stratospheric and tropospheric clouds comprising an undercast.

Less exotic than missiles, perhaps, but much more effective for certain purposes, the sensitivity of manned aircraft to conditions of dense fog, severe storm, extreme turbulence, and the like, is all too well known. In addition to these meteorological factors, information relating to the three-dimensional structure, movement, and intensity of the jet stream; atmospheric layers in which contrails are likely to be generated; and many other weather factors too numerous to mention must be carefully considered by the planner and operator prior to making the final decision.

The tremendous effects of weather conditions on nuclear detonations are now well known. Temperature inversions near the ground and at great heights in the atmosphere, a strong increase of wind speed in the vertical, and a concentration of ozone in the upper atmosphere, all cause the blast effect to be magnified at various distances where successive reflections cause the addition of different wave lengths.

On the other hand, heavy precipitation and fog reduce the effect of the lower overpressures by as much as 50%. A cloud layer below the detonation seriously reduces the thermal radiation. But a cloud layer above the burst will increase the thermal radiation on the ground by as much as 80%. Snow on the ground is also an excellent reflective surface. Only the initial gamma radiation, attenuated solely by the density of the medium through which it passes, is independent of atmospheric conditions.

The radioactive fallout subsequent to the detonation will settle upon the earth's surface—and will be scavenged from the air by rain, sleet, snow or hail—in a huge pattern of death whose orientation, length and width will be determined by the circulation of the wind. And it matters not whether the detonation results from a bomb delivered by a manned aircraft, the warhead of a surface-to-surface or air-to-surface missile, or Polaris. The weather-determined fallout will ensue and must be carefully precalculated, just as the other parameters can and must be predicted—and taken into account prior to the decision.

The exact times of aircraft or missile launch and detonation may, too, be largely dependent upon the weather picture; even the "Go" or "No Go" decision, itself. Of equal importance are Task Force formations, defense measures, and evasive maneuvers, in the event of enemy attack. These should be predicated largely on forecast local weather conditions and the predicted local fallout pattern.

It is self-evident that the operational effectiveness of any vehicle utilizing the earth's atmosphere or hydrosphere as a medium depends upon the accuracy of theoretical design and performance studies utilizing standard and appropriate data. The actual performance depends largely upon the "matching" of actual conditions to the assumed conditions of theoretical studies, and large deviations from standard values can result in serious consequences. Thus, not only must accurate meteorological and oceanographic data be furnished to enable instrument, vehicle, and weapon system design decision, but minimum and maximum deviations from standard must also be furnished to preclude future operational catastrophe.

Despite the passage of time with its associated fantastic developments, the meteorological impact on modern decision-making was most clearly defined fifteen years ago, when CTF 38 included the following conviction in one of his reports: ". . . Those Naval commanders who fail to use weather properly when it is provided, need never fear of losing their amateur status in the game of war. The amateurish conduct of war operations will be in direct proportion to the importance of weather in these operations, regardless of the professional skills of the Command in other fields." And this statement is even *more* valid today than it was in 1945 when it was drafted.

BRIEF ANALYSIS OF THE METEOROLOGICAL FACTOR

So long as an adverse effect can result, meteorological and oceanographic data must be thoroughly considered. But the precise and gainful application of weather and marine aviso to Naval plans and operations requires a certain skill, and particularly an understanding, on the part of all personnel concerned. For, the demand for this information stems from the strong environmental influence exerted on Naval equipment, weapon systems, and personnel.

In some instances, weather information is neither adequate nor properly utilized, for the meteorologist is not always able to produce *exactly* the information which planners and operators state as requirements. Another difficulty stems from the fact that many plans and operations are designed in such a fashion that meteorological information can be applied only once. And the application is usually restricted to the time when operational flexibility has been minimized or eliminated. Thus, in many cases, the weather information must be "single-valued," and an entire decision may revolve around the weakest component.

Fundamentally, meteorological and oceanographic information have maximum value to the Navy only when related to a particular type of operation, and only when this information is transposed into operational factors. The *exact* degree of weather and oceanographic influence is usually difficult to predict. Perhaps in the not-too-distant future it will be possible to state atmospheric and hydrospheric effects with high mathematical precision. But that day has not yet arrived. When it does, it may be possible to transform Naval planning and decision-making into a quantitative mathematical operation—similar to game theory analysis.

Perhaps above all, Naval planners and operational commanders should remember that meteorology is not yet the exact science we would like it to be. The uncertainty factor most assuredly does exist, and should always be taken into account. Also, the value of meteorological and oceanographic information is directly proportional to the flexibility of the plan or operation.

Modern engineering technology can materially reduce the handicap of natural environmental factors. Therefore, meteorological and oceanographic effects on Naval operations should not be continuous. And the degree to which weather and oceanographic influences can be eliminated is largely a function of the Navy budget.

The indeterminacy of weather information has always been rather difficult to manage effectually. But the fact must be recognized that *all* physical systems are indeterminate to some degree. Recent advances in game theory, however, have provided methods for utilizing uncertainty in a completely intelligent manner. And weather data should be handled in the same way in order to exploit their operational and planning value to the fullest possible extent.

CONCLUSION

It goes without saying that this is an extremely complex political, scientific, and technological world in which mankind now finds itself. And perhaps the new and fantastic products of the inventive genius of man have already outdistanced man's proven capability to adjust to their traumatic impact.

Yet, this is the world in which the Navy must plan and operate in the cause of freedom—and must do so effectually and with precision.

One fact, however, remains crystal clear. Despite the continued and tremendous expansion of Naval planning and operations into the vast depths of the hydrosphere and the extreme altitudes of the atmosphere, and despite the advent of the nuclear-missile-space era, the element of weather remains vital to all phases of planning and operations conducted by the Navy. And consequently, the subject of meteorology should be of sound concern to *every* Naval officer.

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GAME THEORY

A lecture delivered
at the Naval War College
12 December 1960

by

Dr. E. Baumgarten

A. *Introduction*

Current planning for the employment of forces in being has to proceed in the face of incomplete intelligence about the numerical strength of the opposition. Estimates of the enemy's operational unit performances tend to be mirror images of our own, which are all too often poorly understood in the present era of rapid weapon development.

Planning for the future has to contend with these same uncertainties in an aggravated manner. It is further handicapped by the unpredictability of technological trends and of the political context five or ten years hence. These indeterminacies make the important procurement and R&D decisions particularly difficult ones.

In addition, statistical fluctuations affect the outcome of any engagement since chance variation is always with us.

Finally, there is the ever-present question of enemy intentions. How will he elect to employ his capabilities to counter our courses of actions? Clearly, enemy reaction has to be considered in all military planning.

This week you are studying one approach to this vexing problem, War Gaming. I am going to introduce you to another one this morning, Game Theory.

Here is a quick run-down on what I am going to cover. I am going to tell you briefly about the origin of Game Theory, define a few terms and develop the basic concepts of the theory by way of an example. I will then show how game theoretical notions are actually being used today in some areas of Naval planning. Finally, I shall make some general comments upon the implications of the use of Game Theory in the planning process.

Since Game Theory is a branch of mathematics I will have to use quite a few charts, graphs and figures. But I promise: No integral signs.

B. The Origin of Game Theory

Game Theory was invented by the late John von Neumann, a very versatile scientist who contributed to H-bomb development and served as an AEC commissioner.

Von Neumann became interested in the analysis of conflict situations a little more than thirty years ago when he was still a student in Budapest. Real life conflicts were at first quite intractable. Von Neumann therefore used a common scientific dodge and studied a more manageable model instead, a stripped version of poker—not strip poker though.

Von Neumann's poker game was reduced to bare essentials to facilitate analysis. For example, only two players are involved. Still the game has enough similarity to more serious conflict situations to be a useful model. Both players try to win at the expense of the other. Neither controls the game by himself. For instance your opponent may not put any money into the pot when you have a good hand and he has a poor one. Decisions have to be made on the basis of fragmentary information. You have to bet without looking at the other player's hand. Finally, there is a statistical element in the game, the order of cards in the deck.

Because of the chance factor probability theory is needed in poker as well as in most military conflict situations. But probability alone is not enough since it does not really help in outguessing the other fellow.

Von Neumann's model studies of poker gave him new insight into the fundamental nature of conflicts and led to the formulation of Game Theory. Game Theory is more ambitious than probability theory. It tries to provide a rational basis for action in the face of intelligent opposition.

Game Theory is not the first instance where a new field of mathematics began with a study of parlor games. The same was true of classical probability theory whose potentialities for insurance underwriting were recognized only after a couple of hundred years.

The accident of birth explains the frivolous name of the theory. It also accounts for some of the terminology. Opponents are players. Players may be individual combatant units, fleets, or whole nations, depending upon the nature of the problem. The only requirement is a common goal. The rules of engagement are the game. A single contest is a play of the game. The outcome determines the payoff. The terminology also has military overtones. The players' courses of actions are strategies, or occasionally tactics.

C. *Game Theoretical Notions*

Let us see next how Game Theory can help in a typical military problem: The determination of an aircraft configuration. The numbers in the example are hypothetical but the problem is a perfectly real one. Here is the situation:

BLUE can equip his bombers with guns or ECM and use high altitude profiles. He can also strip his aircraft in order to penetrate on the deck. The defense, RED, also has several options: A standard interceptor, a low-altitude version, or a fighter with ECCM.

The problem then is a dual one: The best choice of bomber and fighter configurations considering the opposition's range of options. The bomber command wants to maximize his penetration probability while the fighter command wants to minimize this same quantity. Because of lead-time factors both sides have to make their system choices at the same time and in ignorance of that of the opposition. To analyze this situation let us write the nine possible outcomes in the form of a pay-off matrix (Fig. 1). On the left are the three alternatives of the offense. Across the top are the defensive choices. The nine numbers in the matrix are the penetration probabilities. For example, an ECM equipped bomber has a 50% chance of getting through when the defense uses a standard fighter.

By the way, I am going to use the same color convention for the rest of the morning. The maximizing player is always BLUE. His options are listed on the left of the matrix. The minimizing player is RED. His choices are across the top.

Being conservative, the offense looks at the worst that can happen to them, the row minima marked by dots. The largest of these minima in the middle row is called the maxmin and equals 70%. It determines BLUE's safest option. If BLUE settles on stripped bombers, he assures himself of getting through at least 70% of the time.

Conversely, the defense looks at the worst from their point of view, the column maxima, marked by stars. The smallest column maximum in the middle column is called the minmax. It determines RED's safest choice. If RED has low-altitude fighters, he can hold BLUE's penetration probability to 70% or less.

BLUE BOMBER:	RED FIGHTER: ST'D	RED FIGHTER: LOW ALT	RED FIGHTER: ECCM
GUNS	• 40	50	60
STRIPPED	80 ★	•• 70 ★★	90 ★
ECM	50	60	• 40

• ROW MINIMA ★ COLUMN MAXIMA

•• MAXMIN = ★★ MINMAX

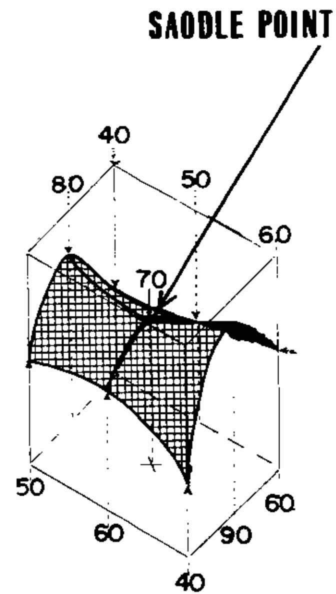

FIG. 1

RED FIGHTER

BLUE BOMBER	ST'D	LOW ALT	ECCM
GUNS	40	50	60
STRIPPED	70 ★	•• 50	80 ★
ECM	50	★★ 60	• 40

NO SADDLE POINT

• ROW MINIMA ★ COLUMN MAXIMA

•• MAXMIN ≠ ★★ MINMAX

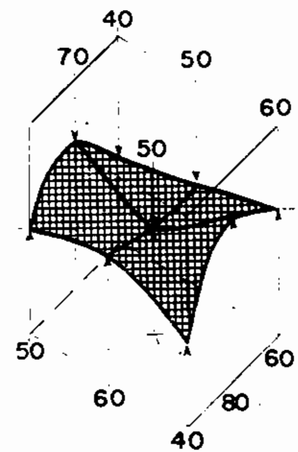

Figure 1 says, in effect, that BLUE should buy stripped bombers and that RED needs low-altitude interceptors. The penetration probability is 70%. This solution is safest for both sides. Bombers with guns or ECM could do worse for BLUE if RED has this low-altitude fighter. Similarly, high-altitude fighters would not do well against the stripped bomber.

Notice that the maxmin equals the minmax in this matrix. A matrix for which this is true is said to have a saddle-point. The reason for this terminology is shown in the little diagram on the bottom of Figure 1. Pay-offs are represented by vertical spikes, with a surface put over the tops. The surface looks like a saddle. The saddle-point is in the center where the penetration probability is 70%.

Whenever the maxmin and minmax are equal there is a nice stable situation. Both sides try to get on the saddle-point. This is equivalent to conventional capabilities planning. There is really no temptation to do anything else.

Saddle-points are not very common, especially in large matrices with many rows and columns. Figure 2 is an example of a matrix without a saddle-point. It was derived from Figure 1 by improving the RED's ground environment and thereby making low-level penetration less effective. Again, BLUE marks the row minima with dots and RED the column maxima with stars. The maxmin and minmax are now different. The pay-off surface given on the lower right of Figure 2 no longer looks like a saddle. This makes the problem much more complicated.

BLUE might figure that he can do better by buying ECM bombers rather than stripped bombers which are really his safest choice. But RED can punish him for doing this by adopting ECCM fighters, if he correctly guesses BLUE's intentions. In other words, there is a conflict between planning on capabilities or intentions.

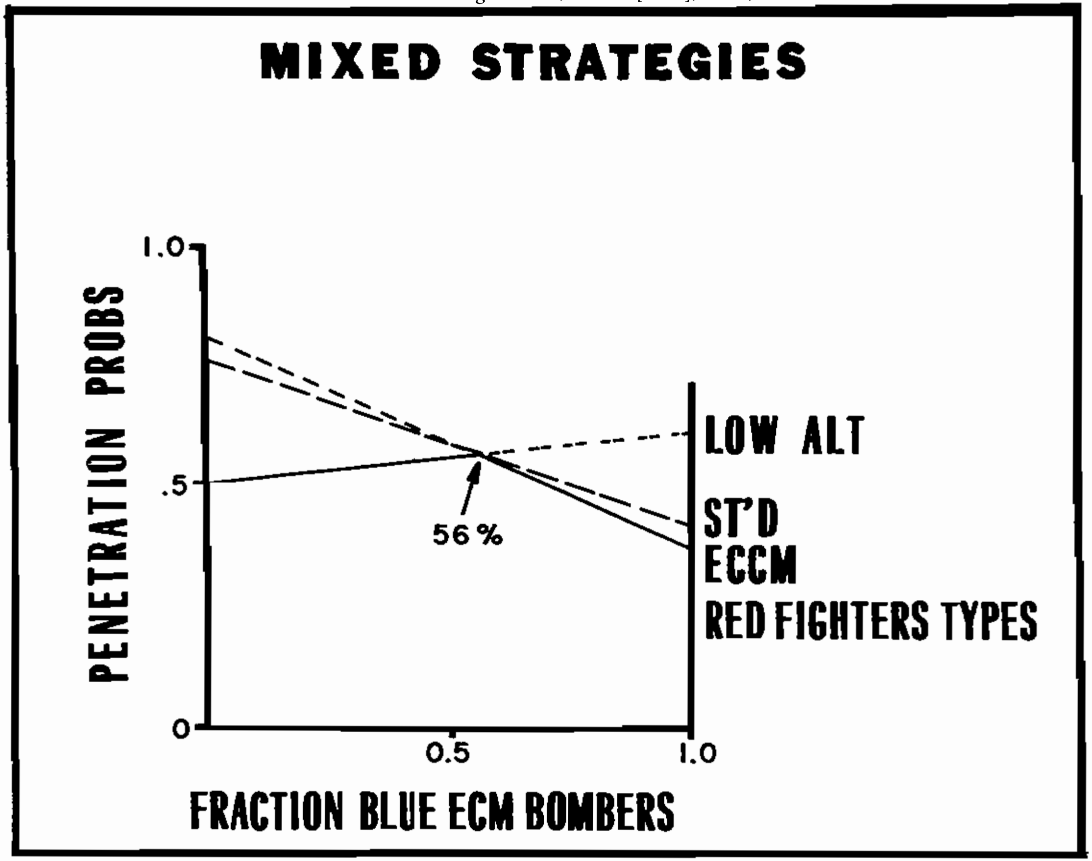
MIXED STRATEGIES
1.0
.5
0
PENETRATION PROBS
56 %
0.5
1.0
FRACTION BLUE ECM BOMBERS
LOW ALT
ST'D
ECCM
RED FIGHTERS TYPES

FIG. 3

Game Theory provides a rational way out of this dilemma. First we note that the pay-offs in the top row are never larger than those in the middle row. BLUE has nothing to gain from bombers with guns, regardless of RED's choice of fighters. We can forget about the top row. But we cannot eliminate any other rows or columns in this simple manner.

Let us now see what happens if BLUE uses stripped and ECM bombers in varying proportions against each of the three fighter types in turn. The analysis is shown in Figure 3. The horizontal axis gives the fraction of ECM aircraft in BLUE's mix. The three lines give penetration probabilities against RED low-altitude fighters, standard fighters and ECCM fighters, respectively.

The intersection is best from BLUE's point of view. It assures him of a penetration probability of 56% with a mixture of 60% ECM aircraft and 40% stripped bombers. A higher fraction of ECM bombers could lower BLUE's penetration probability if RED had ECCM bombers. A lower fraction would reduce the penetration probability in case RED had low-altitude fighters. A similar construction from RED's point of view shows that he should buy 20% ECCM bombers and 80% low-altitude bombers. This mix will in turn insure for RED that the penetration probability does not go above 56%. These mixes again equalize the maxmin and the minmax and stabilize the situation. This analysis assumes that RED cannot match his fighters to BLUE's bomber at intercept time.

The mixed strategies are improvements for both sides over their respective safe pure strategies. BLUE raises his assured penetration probability from 50 to 56%, while RED reduces his maximum risk from 60 to 56%.

In this particular case gains from using mixed strategies were not spectacular. But, of course, every

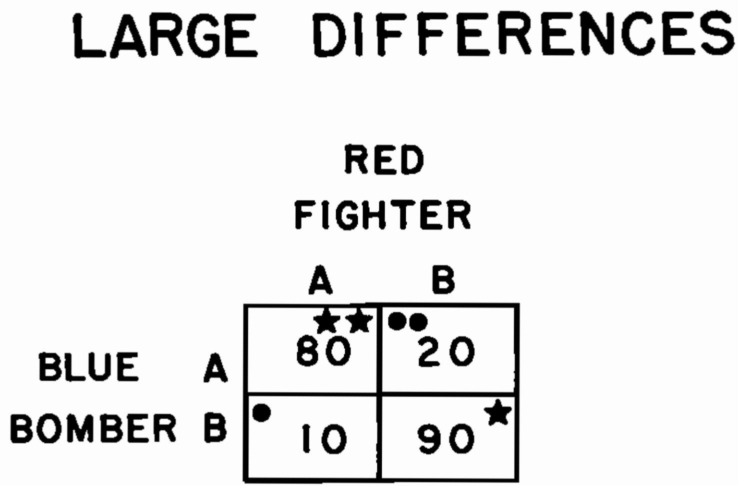

FIG. 4

little bit counts. On the other hand, the gains can be very large when the conditions are right. Figure 4 is a matrix where this is so. The maxmin and the minmax differ by 60%. The penetration probability with the appropriate mixed tactics is 50%. It represents improvements of 30% for each side.

That mixed strategies are, in fact, best for both sides when there is no saddle-point, is one of the central results of Game Theory. Mixed strategies are, of course, only appropriate when both sides have to make decisions in ignorance of those of the opposition. Now the concept of mixed strategy is really not entirely new—you use it intuitively in poker when you consider to fold, call or raise with a poor hand. Game Theory can prove that your intuition is right. You have to bluff some of the time in order to win. But it has not gotten very far in telling you how often to bluff with a given hand. The game has too many ramifications for detailed analysis. The situation in military problems is similar. Some of the simpler situations like the one we have just talked about can be analyzed explicitly. A few solutions have become an integral part of tactical doctrine. I am going to give you an example in a moment. Von Neumann himself had a hand in planning Operation STARVATION, the eminently successful mining campaign against Japan. We get into trouble in case of broader strategic problems. The situations are just too complex. Still Game Theory can often provide a framework for qualitative rather than quantitative study of the situation. This alone is worthwhile. It helps to visualize the consequences of various enemy actions. Clarifying the merits of mixed strategies has been a real achievement of Game Theory. I believe that the potentialities of mixed strategies for combat situations were hardly recognized twenty years ago.

D. A Tactical Application

Let us now see how game theoretical notions have been applied in the formulation of Navy tactical doctrine. The example is one with which you are all familiar, Antisubmarine Screening. But you may not have known that Game Theory played a part in the solution of this problem.

Figure 5 illustrates the general situation. The surface force has to guard against two forms of submarine attack, torpedo spreads launched at long range from outside the screen and salvos fired from near by after the submarine has successfully penetrated the screen. With ample forces, the screen clearly belongs on the boundary of the torpedo danger zone. But with insufficient forces a screen that far out would be practically useless. Escorts have to be brought in closer. When they are too close submarines can take a free shot from outside. The best screen position is somewhere in between. It should minimize the submarine's probability of success. We can find it graphically, as shown in Figure 6.

We plot the submarine's success probability for the inside attack for various screen positions and superimpose the probability of success of the outside attack, delivered from just beyond the zone of sonar coverage. This kind of graph is called a decision diagram.

The solid curves give the damage probability as a function of screen position assuming that the submarine uses his better mode of attack. The lowest submarine success probability is at the intersection of the two probability curves. The crossing is a minmax. It determines the safest defensive disposition. It doesn't matter to the surface force how the submarine attacks when the formation is screened in accordance with this construction. If the screen is farther out submarines should always penetrate. If it

ASW SCREENS

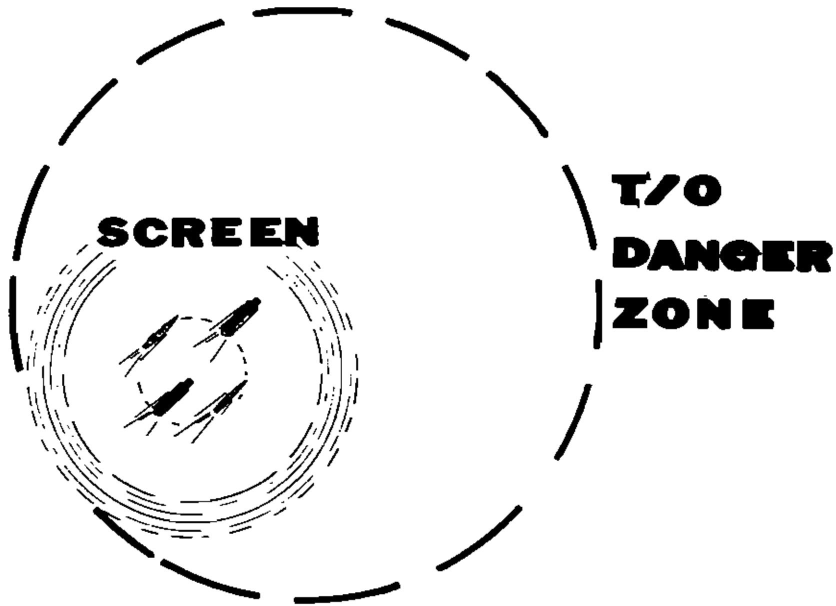

FIG. 5

DECISION DIAGRAM

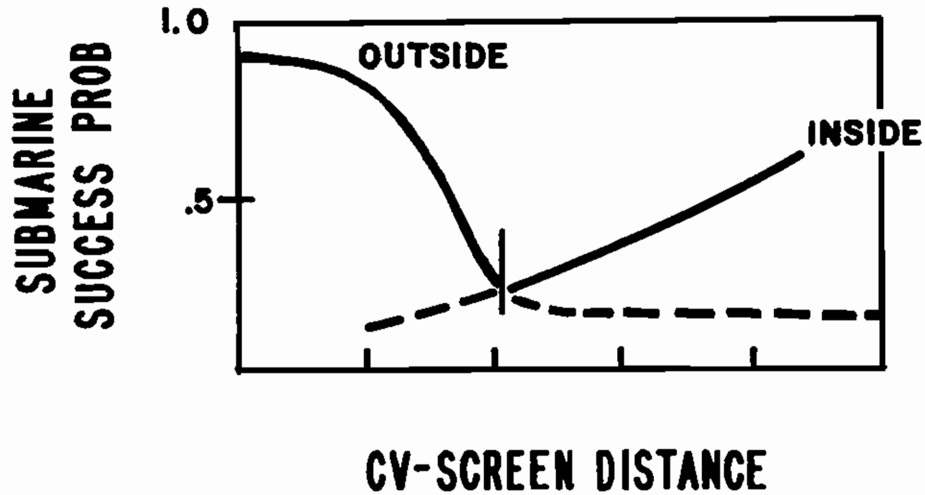

FIG. 6

is moved in they should fire from outside. Smart submarines can inflict unnecessary losses when the surface force departs from its safe screen disposition in either direction.

The screening problem is a special case. The submarine can see the defensive disposition before committing himself and determine on the spot whether to penetrate the screen or fire from outside. The surface force still has to watch how submarines conduct their attacks. If submarines rarely penetrate, the screen should be moved out to meet them. On the other hand, if submarines tend to penetrate frequently, the screen should be contracted. The surface force can get an advantage in either case. Submarines have to guard against this contingency by also mixing their tactics and using inside and outside attacks about equally often, when the screen is placed correctly. Game theoretical solutions are really just points of departure for the beginning of a war. They may need adjustment after the enemy discloses his doctrine in actual operations.

E. A Strategic Problem

So much for tactical applications. In the next few minutes we will explore some of the nasty difficulties we can get into in broader military problems. To do so I am going to acquaint you with Colonel Blotto and his Dilemma. Colonel Blotto is a mythical character invented by 19th century war college strategists. He was later adopted by the game theoreticians. Colonel Blotto appears, for example, in a very nice "primer" of Game Theory by Williams, called *The Compleat Strategyst.* Several copies are in the library. You may be interested to look at one this week.

The Blotto Dilemma is a simple model of the basic strategic problem, the disposition of forces. Actually our example should be called Admiral Blotto's

Dilemma, since it is placed in a Naval setting. Admiral Blotto is a BLUE cruiser commander. We will analyze his problem by following the steps of the standard "Estimate of the Situation":

1. Mission

2. Situation and Courses of Action

3. Analysis of Opposing Courses of Action

4. Comparison of Own Courses of Action

5. Decision

Blotto's *Mission* is to attack RED shipping. Here is the *Situation*. BLUE has two cruisers. Right now two RED convoys are at sea, some distance apart. They are covered by a total of three cruisers. BLUE does not know where the RED cruisers are. BLUE has two *Courses of Action*. He can either send both cruisers out together to attack one of the convoys or he can attack both with one cruiser each. RED in turn is aware of the nature of the threat. He also has two *Courses of Action:* To cover one of the convoys with three cruisers and leave the other one unprotected or give one convoy an escort of two cruisers and the other one an escort of one. Both commanders really have the same basic dilemma: To concentrate their forces or to divide them.

To reduce the problem to the bare essentials we make some sweeping assumptions. The first two are: The two convoys are equally important and all cruisers have the same fighting power. Others will be brought in later.

Writing the *Opposing Courses of Action* in matrix form greatly facilitates the analysis (Figure 7). Again, BLUE's courses of action are on the left, RED's across the top. The entries in the four boxes list the

Analysis of Opposing Courses of Action

BLUE Options \ RED Options	Concentrate	Divide
Concentrate	2 BLUE CL meet either a convoy protected by 3 RED CL or an unprotected RED convoy	2 BLUE CL meet either a convoy protected by 2 RED CL or a convoy protected by 1 RED CL
Divide	1 BLUE CL meets a convoy protected by 3 RED CL The other meets an unprotected RED convoy	1 BLUE CL meets a convoy protected by 2 RED CL The other meets a convoy protected by 1 RED CL

Figure 7

Pay-off Matrix

		RED Options	
		Concentrate	Divide
BLUE Options	Concentrate	$D_2 - 2C$	$\frac{3}{2} D_2 + 1C$
	Divide	$2D_1 - 2C$	$D_1 - 2C$

(C, D, and D_2 are defined in text)

Figure 8

possible encounters. If both commanders concentrate their forces, BLUE's units will either find an unprotected convoy or a strongly guarded one. Chance will govern which one of these two events will occur. If both sides divide their forces, one of the BLUE cruisers will encounter two RED cruisers and the other just one. It should be clear how the other two boxes are filled in.

Unfortunately, the matrix of encounters does not really help us. We have to go further and estimate the pay-offs for each box. To do this, we need some further assumptions. The raiders have to fight the escorts before they can attack the convoys. When equal forces meet either side has a 50-50 chance of winning. The most likely outcome of an encounter between unequal forces is that the stronger side will win without losses. To simplify the matter, let us ignore the less likely outcomes. Let us also say that BLUE inflicts damage D_1, when one cruiser gets through to a convoy. Two cruisers can inflict damage D_2. All cruisers are valued equally, at C. Sinking a RED cruiser adds to BLUE's pay-off; losing one detracts from it. With these rules, we can compute the pay-off matrix from BLUE's point of view.

The algebra is straightforward but a little messy. I will not take time to go through the calculations now. The results are listed in matrix form in Figure 8. It becomes the basis for BLUE's *Comparison of Own Courses of Action.*

BLUE wants to maximize the pay-off, regardless of RED's course of action. He has to assign relative values to D_1, D_2 and C before he can do this. You remember that C is the value of a cruiser. D_1 is the damage inflicted on a convoy by one cruiser. D_2 is the damage inflicted by two. As you will see in a moment, assignment of values is really crucial, since it strongly affects the *Decision.*

The relation between D_1 and D_2 depends upon the rules of engagement between cruisers and convoys. We already dealt with the same kind of problem a moment ago, when we made assumptions about the outcomes of surface actions between cruisers. If a single cruiser can destroy the convoy after it has overcome the covering force, one cruiser can cause just as much damage as two. D_1 and D_2 are equal. This would be true, for example, in case of a small troop convoy. On the other hand, a large mercantile convoy would probably scatter over a wide area before it could be brought under attack. Two cruisers would then be able to sink twice as many ships as one. D_2 would be $2.D_1$.

Determining the relation between the D's and C is even harder. Simple mechanical rules that equate the loss of a cruiser to the destruction of some fixed number of merchant ships in a mechanical manner are wholly inadequate for this purpose. Fundamental considerations of military worth are involved. For instance, place yourselves in the position of the German admiral at Brest, who had to weigh the potential gains from sending SCHARNHORST and GNEISENAU out on a raid against the risk of losing the fleet-in-being. Still, problems of relative military worth have to be faced before coming to a rational decision. This is true, though, whether you use Game Theory or not.

Once the relationship between the D's and C is settled, resolution of the dilemma becomes straightforward. This is shown by the three matrices in Figures 9a, 9b, and 9c. They are derived from the original pay-off matrix in Figure 8 by substituting the assumptions about the D's and C, that I just discussed. The maxmins are again marked by two dots, the minmaxes by two stars. The numbers in the centers are BLUE's expected gains, when he uses his optimum strategy. The answers are, of course, no better than the value judgments invoked in framing the assumptions.

COMPARISON OF OWN COURSES OF ACTION

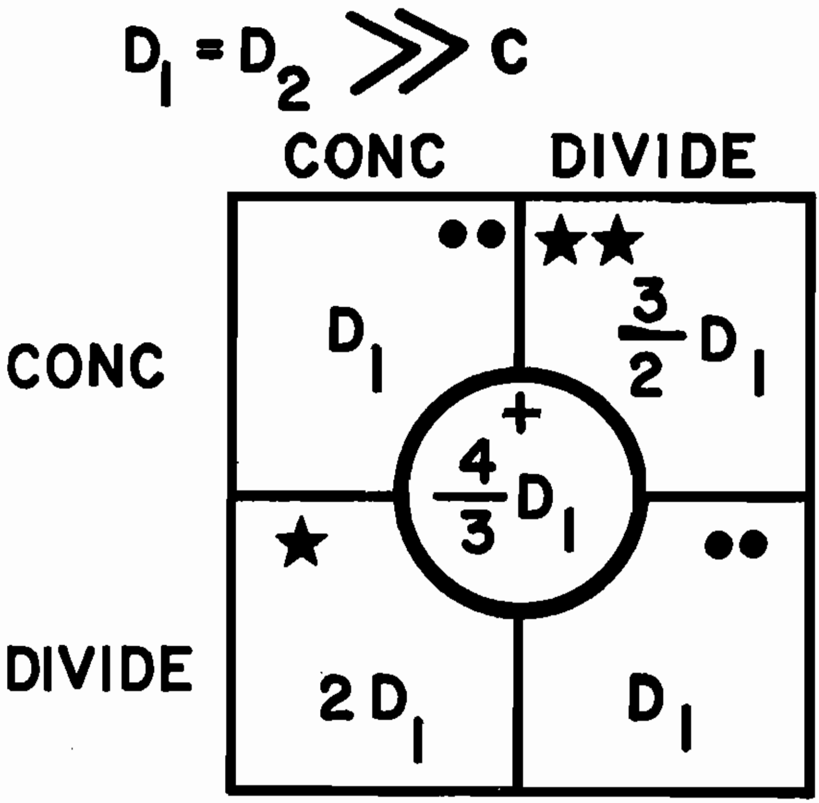

FIG. 9 A

COMPARISON OF OWN COURSES OF ACTION

$$2D_1 = D_2 \gg C$$

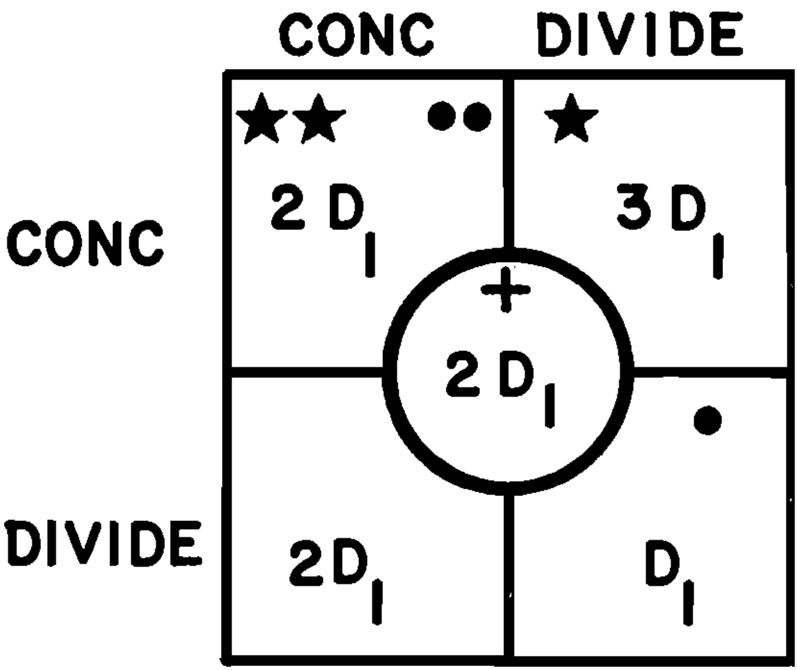

FIG. 9 B

COMPARISON OF OWN COURSES OF ACTION

$D_1 = D_2 = C$

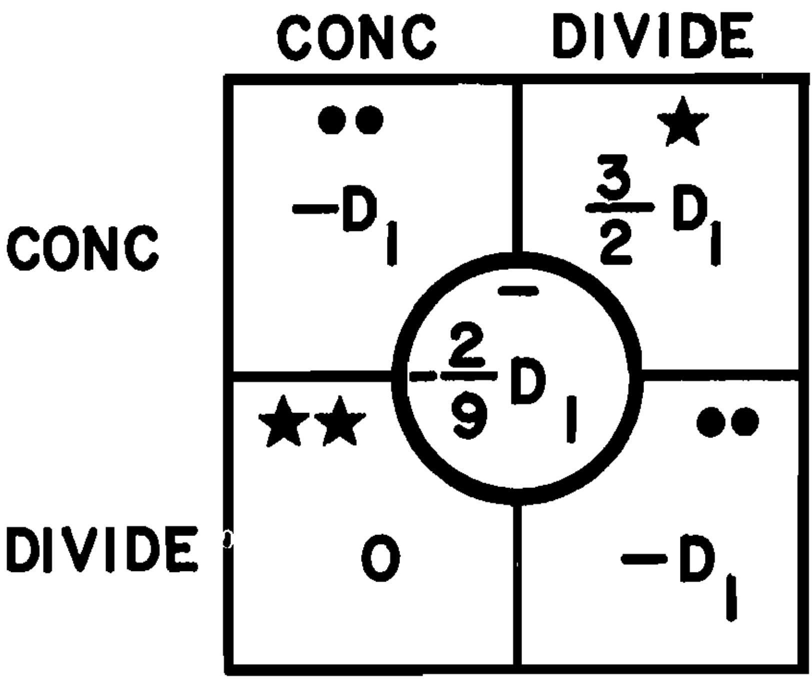

FIG. 9 C

In Figure 9a, D_1 and D_2 are the same and cruisers expendable, i.e., C is much smaller than D_1, ($C \ll D_1$). The maxmin and minmax are different.

The game theoretical *Decision* is as follows: BLUE should use a mixed strategy, determining by some random scheme whether to send the cruisers out singly or together. The best proportions are: together two-thirds of the time and separately one-third of the time. BLUE's expected pay-off is positive. If RED looks at the problem in the same way, he should also use a mixed strategy.

Figure 9b applies when D_2 is twice as large as D_1 and cruisers still expendable ($C \ll D_2$); the maxmin and minmax now become equal. Both sides should not concentrate their forces. BLUE's pay-off is still positive.

The solution changes drastically when BLUE places a high value on his cruisers, the "fleet-in-being" ($C \gg D_1$). This situation is shown in Figure 9c. His expected pay-off becomes negative, even with his optimum mixed strategy. The theory then suggests a radically different *Decision*. BLUE should stay in port and wait for a better opportunity.

F. Conclusion

Instead of reading a point-by-point summary I will close with some general remarks about the military implications of Game Theory.

Game Theory is concerned with the last step in the decision process, the selection of a course of action, or decision.

To do this some preliminaries are required. Possible opposing strategies have to be formulated consistent with the available resources. The probable outcomes for all interactions have to be assessed.

Hence we have to understand the rules of engagement. Outcomes have to be rated in order of preference. This requires a scale of military worth. This scale need not necessarily be quantitative but it must fit the problem at hand.

These prerequisite steps are inherent in every planning problem regardless of the method of solution. They are hard ones and demand the application of professional judgment of the highest order. Game Theory does not help us out of this box. For example, if we omit the winning strategy from the list we merely find a strategy that loses least.

Game Theory and the accepted military decision doctrine lead to identical answers when matched strategies exist. These are situations in which the same course of action is best against enemy capabilities or probable intentions.

The game theoretical approach and the traditional military planning process diverge when the matrix does not have a saddle-point. The game theoretical choice is now a mixed strategy. It can be regarded as a compromise between planning on capabilities and intentions. Following a mixed strategy rather than the safest pure one is a trade-off. It yields a higher expectation of gain at the risk of increasing the chances of an unfavorable outcome. This is still a conservative approach. It appears to be entirely appropriate for the stronger side, which will win as long as it can guide the course of the conflict as a whole in accordance with expectations. The weaker side cannot hope to win unless it adopts a more daring approach.

A mixed strategy only makes sense if the specific choice can be concealed until the enemy has made his move. The side that cannot avoid telegraphing its punches has to stick to strict capabilities planning and pay the price.

Game theoretical solutions are static. They can often be improved upon on the basis of new information, which becomes available as the action unfolds. There are no formal rules for this purpose at the present time.

Military problems are usually far too complicated for explicit solution. Here, Game Theory can still provide a general framework for decision and clarify key issues. But it is never a substitute for experience and good professional judgment.

Finally, a brief comment upon the relationship of Game Theory to War Gaming. Both try to come to grips with the same fundamental difficulty, the problem of enemy reaction. They tend to complement one another.

Game Theory can screen out unpromising strategies and find good mixtures for further investigation by gaming techniques.

War Gaming can help evolve a set of strategies for a game theoretical analysis. It can also give a better understanding of the rules of complex engagements.

Both may get us into trouble if inputs are in error or if the implicit value judgments are inappropriate for the real problem.

BIOGRAPHIC SKETCH

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Schools:

1940 - California Institute of Technology, B.S. Degree.
1941 - University of California (L.A.), M.A. Degree
1943 - Duke University, Ph.D. Degree.

Career Highlights:

1943-44 - Research Engineer, Am. Gas Assn.
1944-46 - Research Engineer, The Best Foods, Inc.
1946-52 - Research Chemist, Am. Cyanamid Co.
1952-date - Operations Evaluation Group, OpNav. assignments follow:

1953-54 - Assignments to CARDIV's 14 and 18.
1954-55 - Staff, COMANTISUBLANT.
1955-56 - Scientific Analyst, Submarine Branch, OpNav. (Op. 311)
1956 - Project NOBSKA.
1956-58 - Assistant to Director, NAVWAG (Op. 93R).
1958-59 - Staff, COMFIRSTFLT.
1959-61 - Staff, Naval War College.

RECOMMENDED READING

The evaluation of books listed below include those recommended to resident students of the Naval War College. Officers in the fleet and elsewhere may find them of interest.

The inclusion of a book or article in this list does not necessarily constitute an endorsement by the Naval War College of the facts, opinions or concepts contained therein. They are indicated only on the basis of interesting, timely, and possibly useful reading matter.

Many of these publications may be found in ship and station libraries. Certain of the books on the list which are not available from these sources may be available from one of the Navy's Auxiliary Library Service Collections. These collections of books are obtainable on loan. Requests from individual officers to borrow books from an Auxiliary Library Service Collection should be addressed to the nearest of the following special loan collections:

Chief of Naval Personnel,
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Department of the Navy
Washington 25, D.C.

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U.S. Naval Station
(Attn: Station Library)
San Diego 36, California

Commandant FOURTEENTH Naval
District (Code 141)
Navy No. 128
Fleet Post Office
San Francisco, California

Commander Naval Forces,
Marianas
Nimitz Hill Library, Box 17
Fleet Post Office
San Francisco, California

U.S. Naval Station Library
Attn: Auxiliary Service Collection
Building C-9
U.S. Naval Base
Norfolk, Virginia

BOOKS

Davids, Jules. *America and the World of Our Time.* New York: Random, 1960. 597 p.

In this book Mr. Davids has given his answers to many questions, such as: How did the United States' rise to world leadership take place? What were its causes? What were the events that we can now, in retrospect, consider to have been the milestones along this road to the global responsibility that is America's today?

Niebuhr, Reinhold. *Reinhold Niebuhr on Politics.* Edited by Harry R. Davis and Robert C. Good. New York: Scribner, 1960. 364 p.

This book is a well-edited (by two political scientists) compilation of excerpts from both systematic and sporadic writings of one of the great theologians of our time, presenting his statements and analyses of the most significant philosophical and theological problems with us today. In this volume the reader is given a condensation and crystallization of serious thoughts on such subjects as Communism, Nazism, democracy, political power and the nature of politics, international relations, world government, pacifism and related items.

Morgenthau, Hans J. *The Purpose of American Politics.* New York: Knopf, 1960. 359 p.

Dr. Morgenthau has undertaken to define the national purpose by evaluating our political background and in so doing concludes that the national purpose is now facing a major crisis caused by the equalitarian approach to alliances, majority government and committee rule, excessive influence of public opinion, conformism and the rise of a new form of feudalism. These causes are attributes to the maintenance of a material and political status quo. This work of Dr. Morgenthau is a thought-provoking and readable book, recommended to all having interest in the political struggle taking place in the world today.

Hayes, Carlton J.H. *Nationalism: A Religion.* New York: Macmillan, 1960. 187 p.

As the title implies, the author develops the thesis that modern nationalism, born in Europe and Anglo-America some 150 to 200 years ago, and more recently embraced by most of the rest of the world, has all the aspects of a religion, and he leaves it to the reader to decide for himself that it has been the dominant religion in the industrialized countries of the world.

Furnia, Arthur H. *The Diplomacy of Appeasement: Anglo-French Relations and the Prelude to World War II.* Washington: University Press, 1960. 454 p.

Based on both published and unpublished diplomatic correspondence, and extensively annotated, this text affords a wealth of material for the serious student of international relations. It is, however, difficult reading for the layman, since the analytic treatment of events presupposes a scholarly knowledge of European politics.

Smith, J. Malcolm and Cornelius P. Cotter. *Powers of the President During Crises.* Washington: Public Affairs Press, 1960. 184 p.

This book, an exhaustive examination of the *emergency power* of the President, fills in one of the most serious gaps in the available works on the Presidency. In addition, it reveals a graphic picture of the broad extent to which emergency power has been used by the Government of the United States in recent years.

Roskill, Stephen Wentworth. *White Ensign: The British Navy at War, 1939-1945*. Annapolis, Md.: U.S. Naval Institute, 1960. 480 p.

White Ensign is a short account of the British war at sea from 1939 to 1945, written in response to a request of the U.S. Naval Institute. It is one of a series that deals with World War II from the point of view of the major participants. Earlier volumes have been written by German, Italian and French authors.