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MATHEMATICS IN COMBAT

By

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13. ABSTRACT

The purpose of this book is to familiarize the reader with how mathematics can solve important problems in modern military affairs. The authors discuss and explain, without resorting to complex mathematical calculations, the essence of the basic methods which modern mathematics makes available to military problems, design and combat deployment of modern weapons.

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FROM THE PUBLISHER

This book will assist the reader lacking a special background in becoming familiar with how mathematics can solve important problems in modern military affairs. The reader will become familiar with new and rapidly developing trends in mathematics that are revolutionizing the military. This book was written by a staff of authors. The articles contained herein are written in the laymen's language, are interesting and are intended for military and civilian personnel, agitators, propagandists, lecturers and instructors.

Composing editor: Lt. Col. Engineer V. N. Zhukov.

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INTRODUCTION

Marx called mathematics a potent tool of knowledge. The scientists that work in this science do not build machinery, mills, buildings, are not directly involved with telescopes or cyclotrons, but their participation is indispensable to designers, physicists and astronomers. Even military development is inconceivable without mathematics.

Mathematics, like any other science, was born out of the needs of life. The military, along with industry, posed many problems for mathematics. Every possible calculation has long been used in the construction of fortifications, for determining the location of ships on the sea or for aiming artillery.

The need for mathematics grew even greater in the 20th century. The exceedingly complex weaponry and the vast scales of its deployment gave rise to the need for special methods whereby combat operations could be carried out most effectively. These methods were first developed during the course of World War II. During the postwar years, marked by revolution in military affairs, stimulated by the appearance of nuclear missile weaponry and its acceptance by the armed forces, these methods were very quickly perfected.

It is now impossible to imagine the creation of new weapons without the active participation of mathematics. This science became enormously important even in the organization of military actions. In order, indeed, to effectively control the armed forces in modern combat it is essential to collect, process, analyze and transmit to subordinate units, elements and higher headquarters in as short a period as possible an enormous quantity of data pertaining to field observations, administration, supply and troop transportation. The problem is complicated by the rapid change in conditions under which the forces are administered, by the fast pace of modern combat and by the fact that it is essential to concentrate or disperse forces as rapidly as possible. All of this compels the search for and development of methods that enable a commander to solve complex and laborious combat problems within short periods. Such methods are also exceptionally important in the development of new tactical methods, preliminary evaluation of weapons prototypes and instruction of personnel.

Finally, the mushrooming development of electronic computers and their introduction to the armed forces posed different problems concerning the use of mathematics in the armed forces. The computers opened new paths to the solutions of military and design problems. Before computer technology could be used, however, these problems first had to be translated into the language of mathematics, the language of numbers and equations.

One should not gain the impression, of course, that mathematics in military affairs opposes tactics, operational skill or deprives a commander of the creative approach to the solution of military problems. The commander has the last word and in the final analysis his intelligence and will determines success, no matter how far automation advances in the army and navy, no matter how perfect the mathematical methods he employs. It can be said with certainty, however, that he who knows and uses extensively the various capabilities of mathematics will perform most successfully in combat.

All of this must be considered in the education and instruction of Soviet troops. Marshal of the Soviet Union R. Ya. Malinovskiy once said: "We must all understand that without a high level of technical preparation of all personnel, without a knowledge of the fundamentals of physics and mathematics, the efficient use of modern combat technology is now impossible."

The volume of literature devoted to the introduction of mathematical methods to science, technology and economy, now available in the book market, is expanding at an ever growing rate. There are many fewer books related to the military application of mathematics. Those that are available, in fact, are generally written for the educated reader, largely the engineer. There is an urgent need for a popular textbook whereby military readers who lack special preparation can become familiar with fundamental military problems, the solutions of which require the use of mathematics, with the mathematical methods that elevate to a new level the control of troops in combat, development of armament and new tactical methods, processing of reconnaissance and other information.

The book *Matematika v Boyu* [Mathematics in Combat] is offered as such a textbook. It includes revised articles by military specialists, published in recent years on the pages of the newspaper *Krasnaya Zvezda*. The authors accepted a difficult challenge: to explain, without resorting to complex mathematical calculations, the essence of the basic methods which modern mathematics makes available to military problems, design and combat deployment of modern weapons. Some of the discussions, perhaps, lack the required mathematical rigor and completeness. The authors are hopeful, however, that the reader, having become interested in the problems set forth in the articles, will turn to more thorough publications and thereby even further expand his military theory horizon.

MATHEMATICS AND MODERN WARFARE

Captain 2nd Class V. Abchuk, Candidate of Naval Sciences

Every school child knows that it is impossible to build even a simple machine, building, bridge or ship without calculations, without using the laws of mathematics. And everyone understands that the military revolution, manifested primarily in the appearance of the most powerful means of destruction -- nuclear missiles, could not have occurred without the extensive use of mathematics.

The splitting of the atom and practical creation of nuclear bombs, the design of missiles and determination of the laws of their motion would have been impossible without it. The most complex principles of operation of modern radio electronic systems, the possibilities of further improvement of the combat properties of aircraft and submarines have been investigated by means of mathematics. Mathematics, in a word, was the unique tool with which were created the numerous forms of modern military technology that determine the present appearance of the armed forces.

To speak thus, however, is to paint only part of the picture, to explain only one aspect of the role of mathematics in modern warfare. Indeed the appearance of nuclear missiles caused enormous shifts in the entire military structure. It led to re-examination of the views on the deployment of the armed forces in warfare, altered the traditional concepts of tactics, operational skill and strategy. It became necessary to reorganize control of military actions. And this also was inconceivable without the extensive use of mathematics.

The organization of control in combat has always been a tough problem. In our time, however, new problems have arisen. First of all the volume of information concerning the rapidly changing situation in the three spheres -- land, air and sea, has expanded explosively. Moreover the strict requirement of instantaneous reaction to a change in the situation has been imposed, since hesitation in missile warfare leads to destruction. Under such conditions special requirements are imposed on the decision of a commander in the conduct of military actions. It must take into account the overall complexity of the situation and at the same time be correct and quick. The requirement of justification of a combat decision also existed in past wars. The difference here consists in the fact that the elementary calculations and rough estimates, based on the personal experience and intuition of the military commander are replaced by methods of analysis borrowed from the arsenal of the exact sciences or specially developed for military problems. Mathematics is the most important of these methods. Its role, however, is not limited to this. Electronic computers -- automatons, can be used extensively for the complex and rapid calculations required for decision making. And mathematics is the language of these machines. Thus mathematics is simultaneously a tool for decision making and the language for its preparation by means of computer technology.

What branches of modern mathematics are used for substantiating the commander's decision in modern warfare? First of all, of course, are mathematics, algebra and geometry. These have long been the inalterable attributes of all military calculations and do not require special explanation. Now employed in military affairs, along with them, are such mathematical disciplines as the theory of probabilities and mathematical statistics, information theory, theory of mass services, search theory, mathematical planning, mathematical simulation and games theory. In those fields of military matters where the qualitative approach to processes and phenomena once reigned supreme, they permit the use of more thorough and perfect quantitative laws.

Probability theory is the branch of mathematics that investigates the laws of random phenomena. Since military actions conducted even under identical conditions unfold differently each time, the phenomena that comprise these actions are of a random character and the laws of probability theory are applied to them. A knowledge of these laws enables one to predict the possible outcomes of combat or an operation and to calculate the forces required for the solution of the stated problem and to find the optimal variant of its execution.

We will discuss such an example. Suppose it is established as a result of tests that of 100 missiles launched 70 reach their targets. In the language of probability theory this means that the probability of the missiles reaching their target is 70%. The commander, in order to make a decision, must calculate the number of missiles that must be launched to ensure that one of them reaches the target. Without a knowledge of probability theory it is impossible to answer such a question correctly. Meanwhile this theory permits determination of the required military reserves with scientific reliability. The following result is printed out for the above-stated conditions: the required number of missiles is two.

It is obvious from the above example that certain experimental data must be available in order to use probability theory. Mathematical statistics deals with the processing and analysis of the results of diverse tests. It prepares the foundation for subsequent application of probability theory and other mathematical methods. Hence the ever increasing significance of test data gathered from the firing of weapons, testing of military hardware and tactical exercises becomes clear. These data are a source without which it is impossible to use effectively the mathematical methods of decision making.

From the point of view of the science of control, cybernetics, the preparation, working out and realization of a decision on the part of a commander is no different from the collection, processing and transmission of information. And the quantitative laws related to the collection, transmission, processing and storage of information are the subject of information theory. Information theory makes it possible, during the process of development and realization of a decision, to solve successfully certain complex problems of troop control, to establish conditions under which it is possible in the given situation to obtain the most complete reconnaissance information and to find the answers to other important questions.

The theory of mass servicing, by which it possible to make a sound decision in such situations when it is essential to secure (service) a number of objectives with limited forces or equipment having certain combat capabilities, is also being employed in the military. We will explain this by way of an example.

Suppose that the PVO [Protivovozdushnaya oborona; Air defense] system of an objective consists of four zones. In each zone there are two identical antiaircraft missile installations, and either of them can fire upon and destroy one airborne target. The attacking aircraft, trying to reach the defended target, must obviously pass consecutively through all four zones, retaining their combat viability. Generally speaking, in order to make a decision as to the organization of air defense it is extremely important to calculate the number of airborne targets that can penetrate the PVO system or a part of it. In our example it is essential to know how many targets will penetrate one zone, two zones, etc. Using the theory of mass servicing it can be determined that of 100 targets 50 penetrate the first zone, 20 the first and second, 5 the second and third, and not more than one target of the 100 penetrate all four zones.

The commander will make the right decision only if he can take into account the entire set of factors that determine the success of combat. One of such factors is timely detection of the enemy as a result of reconnaissance. A special mathematical discipline -- reconnaissance theory, analyzes the quantitative laws inherent to the process of observation and reconnaissance. Here the character of mutual movements of friendly forces and enemy forces leading to convergence on the effective range of the observation systems is analyzed, the laws of detection of various targets are determined and the most effective reconnaissance methods are established.

For the solution of certain important military problems the correct planning of military actions and the choice of the optimal distribution of forces and systems for the dealing of destruction to the enemy are essential. In this case we resort to the aid of mathematical planning. A group of submarines, let us say, poised in firing position, must launch missiles against several different shore targets, where the probability of destruction of these targets by the various submarines is not the same. Mathematical planning makes it possible to distribute the missiles among the targets so that maximum punishment is delivered to the enemy.

The development of mathematical descriptions of combat actions or, in other words, mathematical simulation of war, is becoming increasing important in connection with the ever expanding use of computers for the solution of strategic and tactical problems. In fact, the solution of combat problems by computer is possible only if these problems are translated into the language of mathematics, presented as certain mathematical functions. Mathematical models make it possible to analyze possible situations ahead of time and to arrive at important practical conclusions even before combat operations begin.

The so-called Lanchester equations are the simplest form of mathematical simulation of combat. They represent a system of differential equations that describe hostilities between two groups of homogeneous combat units. This model, despite its exceedingly simplified character, produces a number of interesting conclusions. One of them, for example, is that the overall effectiveness of a given quantity of troops and machinery is equal to the average effectiveness of each combat unit, multiplied by the square of the number of such units participating in combat.

Certain victory in modern warfare is possible only when the high technological development of the enemy, the fact that he is armed, reacts sensitively to all actions launched against him and is opposed to our flexibility, are constantly taken into account. And mathematics presently affords special methods whereby enemy responses can be predicted and the best tactics under conditions of enemy counteraction selected. Such methods are known as games theory. This theory concerns analysis of so-called conflicting situations -- situations in which two or several sides have conflicting interests.

We will consider such an example. A submarine attacks an enemy surface vessel with torpedoes. Modern torpedoes can be both homing and without a homing system. Obviously the different types of torpedoes have different probabilities of destruction of a surface vessel. The enemy, however, will obviously not know which torpedo the submarine launched. On the other hand the submarine commander also does not know what type of retaliation the enemy will use or with what means he will attempt to act on the torpedoes. The use of games theory in such a conflicting situation enables the submarine commander to select the best tactics and to come up with recommendations concerning how often to use one or the other type of torpedo.

As we have seen, the methods of mathematical analyses in combat are extremely diverse. In all situations, however, their main purpose is to substantiate the most effective means of carrying out military actions. Of all possible solutions that one which ensures greatest success is selected. In order to substantiate the choice of the best or, as the mathematicians say, optimal solution it is necessary to know how to compare the results of military actions from the point of view of their effectiveness or success. Special indices, called effectiveness criteria, are used for this purpose. They play an extremely important role in military mathematical analyses, the ultimate purpose of which consists in the search for and comparison of the criteria of effectiveness of different means of carrying out combat actions and determination thereby of the ways to improve these actions and the operation as a whole.

What should the effectiveness criterion be and what must be borne in mind when selecting it? First of all, the effectiveness criterion should be aimed at the solution of the principal task of the examined military action, upon which primarily depends the success of combat. This is readily seen in the following example.

During World War II antiaircraft guns were installed on British and American merchantmen, by means of which attacks by German aviation were reflected. The number of downed aircraft, however, was slight -- approximately 4% and the cost of installing and servicing the guns was quite high. In this connection they began to remove the antiaircraft installations from the transports. Before such a decision was made, however, a mathematical analysis was undertaken. It was discovered first of all that the correct conclusion could be reached only after selecting a criterion corresponding to the principal task -- preservation of the maximum number of ships. From this point of origin the losses in transport ships were used as the effectiveness criterion rather than the percent of downed aircraft. And it turned out that these losses, thanks to the reduced bombing accuracy of aircraft under fire from the antiaircraft guns, compared to the bombardment of unarmed ships, were reduced from 25% to 15%, i.e., cut nearly in half. Consequently the perfect advisability of equipping transport ships with antiaircraft weapons was absolutely determined.

The effectiveness criterion, as seen in the above example, must be selected in quantitative, i.e., numerical form. Other and, incidentally, extremely common formulations characterizing the success of combat actions, for example "high effectiveness," "substantial losses," "negligible success," cannot be used as effectiveness criteria. Indices of success, based on probability, are widely used in military mathematical analyses. They are known as the probability criteria of effectiveness. They are useful in finding the solutions of many important military problems.

Suppose that it is necessary to determine the number of antiaircraft missiles that should be concentrated on one airborne target for sufficiently reliable target destruction. The probability of destruction of this target by one missile or by a salvo of two, three or more missiles, is used as the effectiveness criterion in such cases. Calculations show that the probability of target destruction by two missiles will be 96%, and by eight missiles about 100% for a probability of target destruction by one missile equal to 80%. The stated effectiveness criterion shows clearly that it is better to use a salvo of two missiles and thereby save the six missiles that yield only a slight increment in the probability of target destruction.

Also used extensively, in addition to probability criteria, are success indices, which can be called productive, since they characterize the "productivity" of planned or executed combat actions. We will examine the following problem: an observer, in an aircraft, ship or tank, carries out reconnaissance of the enemy with the aid of observations systems. At what speed should the observer travel to ensure the most successful reconnaissance?

It would seem at first glance that the higher the speed during reconnaissance the better, and consequently the observer should travel at maximum possible speed. The faster the observer travels, however, the shorter the range of observation. The correct answer is readily found if reconnaissance "productivity" -- the area scanned by the observer per unit of time -- is used as the effectiveness criterion. The speed at which "productivity" is maximum will also be the most suitable.

The above example shows that the effectiveness criterion must characterize combat action from different points of view. Thus, one must not rely simply on one requirement of increasing speed when selecting a suitable method of actions during reconnaissance; it is also essential to consider the dependence of the range of observation on the rate of travel of the observer.

The main directions in which the effectiveness criteria are used are the choice of armament, determination of the best means of deployment of forces, evaluation of the correctness of the tactics chosen.

The probability of target destruction by some type of weapon is customarily used as the effectiveness criterion for the choice of weapons systems. Here not only the power of the examined weapon, but also possible enemy counteraction, are taken into account. The more powerful a weapon the higher the effectiveness criterion becomes, but the stronger the enemy's counteraction on the effectiveness of the weapon deployed, the smaller the criterion will be. Preference is given to forms of weapons for which the criterion -- probability of target destruction with consideration of its counteraction -- is maximum.

Consider two antiaircraft systems -- A and B. Suppose the probability of destruction of an airborne target by system A without consideration of target counteraction is 90%, and for system B -- 60%. If, however, the target begins to offer counteraction, for example interferes with the guidance apparatus of the antiaircraft weapon, the probability of target destruction by system A decreases to 40%, and by system B to 50%. When the probability of target destruction with consideration of its counteraction is used as the effectiveness criterion it is better to deploy system B.

The use of effectiveness criteria for substantiation of the best means of deployment of forces can be traced in such an example related to the Second World War. The American command, faced with the threat from German submarines, had to decide how best to use the limited number of aircraft at its disposal: send them against the enemy submarine bases or use them for protection of convoys at sea. The number of ships that could be saved as a result of 100 flights was used as the effectiveness criterion. It turned out that in the case of attacks on the submarine bases an average of 12 transports were saved per 100 sorties, while protection of the convoys at sea saved 15 Preference, naturally, was given to the latter course of action.

Evaluation of the correctness of a selected course of actions on the basis of analysis of the results obtained is very important in a combat situation. Such an evaluation can be made by comparing the theoretical effectiveness criterion with the achieved. Thus, a commander, preparing to execute reconnaissance, can calculate his expecte' roductivity" ahead of time. During the course of reconnaissance he can ılate on the basis of the results, using special equations, to what the actual "productivity" is equal. Comparison of it with the expected will also yield a criterion for judging the correctness of the executed actions. If the result achieved is approximately equal to the expected result the commander acts correctly, but if it is less then it is obviously necessary to reanalyze the solution and change the tactics in accordance with the circumstances -- new enemy weapons, new tactical methods, etc.

It should be pointed out by way of conclusion that the examined mathematical methods comprise the foundation of one of the most important branches of military science -- methods of operations analysis (or of combat actions analysis). By using a combination of different mathematical methods operations analysis accomplishes scientific analysis of combat actions and provides commanders with quantitative data for reaching a decision. Widely used here are both electronic computer technology and methods of small-scale mechanization and automation of strategic-tactical calculations.

In order to master the modern means and methods of decision making in combat it is essential to have, in addition to a broad military background, a good mathematical preparation and to know how to use mathematics for combat calculations. That is why our days, marked by revolution in military affairs, mastery of mathematics has become an indispensable part of the professional preparation of officers.

STATISTICS AND PROBABILITY

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In nearly every step we take in our daily routine we encounter phenomena and events of a random character. Arising in the morning we look out the window with doubt, even though yesterday's weather forecast was extremely encouraging. On the way to the firing range we cannot accurately predict the results, even though we are certain of success. Traveling by municipal transport on a familiar route, we cannot guarantee how long the trip will take. We are annoyed at finding a typographical error in a book, even though we know that the author, editor, proofreader -- an entire staff carefully checked the manuscript and proofs, and the error is clearly random.

In industry, analyzing a lot of products, for example mass-produced vehicles or aircraft, manufactured according to the identical blueprint with the very same equipment, we are often convinced that individual specimens differ somewhat by weight, engine power and other specifications. These are random deviations from the desired result.

It is easy to see that the above examples pertain to the realm of purposeful human activity -- activity subordinate to a certain plan, aimed entirely at specific goals. It is precisely such type of activity that constitutes the daily life and work of our national economy, army and navy.

But what do our examples signify? Perhaps we have here correctable deficiencies in industry, transportation and in the weather bureau. Perhaps more diligent work on the part of the editorial staff can guarantee that there will be no distortions of the text. If the question is presented in a more general form, it reads as follows: can purposeful activity be organized in such a way as to preclude randomness, to ensure "absolute" precision in achieving the stated goals?

Man in his purposeful activity is involved with systems in the broadest sense of the word, i.e., with a set of interrelated elements. Here by elements we may mean even the fundamental particles of matter, combinations of which make up the entire diversity of the world. The goal of human activity is to bring various systems into certain states from some initial state. This activity, however, proceeds on the level of the knowledge of matter, and consequently of the object of human interest, his environment, that is determined for the given level of scientific development. Therefore it is theoretically impossible to guarantee total achievement of a desired result.

That, however, is not all there is to it. If we examine, rather than purposeful activity, the law of development of some system in general, such as the development of the solar system, then we cannot say with certainty that some state of the solar system determines uniquely all its subsequent states. A change in the conditions under which the system functions, a change in its ties to the environment has an effect on the development of the system. This is manifested in the form of random actions and under certain conditions may lead to regular changes.

Thus, an answer to the stated problem has been found, and the answer is negative. But why then, ask the skeptics, pose problems, strive for goals, if the goals cannot be reached with absolute precision? And others reply: "Begging your pardon, but indeed successes on the path of purposeful human activity are evident, nuclear power plants, in fact, are operating, spacecraft are successfully reaching the prescribed orbits and a never ending stream of automobiles and combines is leaving the assembly lines."

We will try to resolve such doubts. There is nothing strange in the negative answer which we have obtained. In the development of any system there are completely defined statistical laws. They are such that a given state of the system determines all subsequent states not uniquely, but with only a certain probability. This probability is an objective measure of the possible existence of tendencies of the system to change.

Statistical laws are usually manifested either in the conditions of development of a single complex system due to the massive character of random actions, or in those cases when a set of like systems exists under identical conditions. In complex systems the combined action of a large number of random factors leads, as a rule, to results that are almost independent of chance; at work here is the so-called law of large numbers. When, indeed, there is a set of homogeneous systems that have developed under identical conditions, such laws are at work once again -- the average result for the set is almost independent of chance.

The law of large numbers is an objective law of the material world. It yields to quantitative estimates, which are examined by a special science, the theory of probabilities. Therefore, wherever the law of large numbers operates, the methods and results of this theory can be used successfully.

Even before the appearance of probability theory, of course, man successfully carried on purposeful activity. This activity was successful, however, only to the extent that it agreed with the objective laws then in force. It is now difficult to find a field of science, industry, technology that does not make use to some degree of the theory of probabilities. It is even indispensable in the military. This, however, in no way means that probability theory is any "science of sciences" or the most "general" science. It is applicable only where the law of large numbers holds true and enables us to find and use objective statistical laws in random phenomena.

As regards the possibilities of solving practical problems, they are determined by the present level of development of this science and also by the level of statement of problems. The fact is that probability theory is a mathematical, i.e., exact science. Exact sciences work with magnitudes and numerical characteristics related to real systems and objects under investigation. This means that in those fields where our knowledge is limited to a description of phenomena without their quantitative analysis, attempts to use probability theory are futile. Thus, for example, is the situation in certain fields of geography, as it was until recently in medicine and linguistics. It can be said that there are such fields, even in the military, where principally descriptive methods are used. Description and accumulation of facts, however, are only one stage of knowledge, and it is always followed by analysis and generalization.

We have already observed that probability theory analyzes the general laws of random phenomena, regardless of their specific nature, and proposes methods of quantitative analysis of the effect of random factors under different conditions. One of the most important concepts of this theory is random event. Events which may or may not occur under certain constant conditions are called random events. A winning lottery ticket or malfunctioning of a radio receiver during transmission are examples of random events.

The realization of conditions under which random events occur is called "a test." Shooting at a target, for example, is such a test. If tests are repeated under identical conditions, let us say the same marksman shoots at the same targets, from the same range, and with the same rifle, the average result will be amazingly stable: the percentage of tests that are terminated by a random event will approximate some constant. This constant is called the probability of the given event.

Thus, if under certain specific conditions a marksman hits the target an average of 95 times out of 100 shots it is said that the probability of hitting the target in this case is 0.95. If during mass production under certain conditions an average of 7 out of every 1,000 units of finished product are rejects, it is said that the probability of reject of the given enterprise is 0.007.

We will denote the probability of event A through p(A). The probability of any event cannot be less than zero or greater than one. If the probability p(A) is close to one it means that the event is frequent. If probability p(A) is close to zero, event A is rare.

In order to solve practical problems it is necessary to determine beforehand how close to one the probability of an event should be before it can be considered reliable for practical purposes. Or otherwise, how small should the probability be in order that an event can be safely considered impossible.

If, for example, 0.95 is the probability of malfunctioning of fire extinguishers (they operate effectively in only an average of 95% of all cases), then that lot of fire extinguishers cannot be considered satisfactory. If, however, 0.95 is the probability of sprouting of a seed, the germination of the consignment of seeds can obviously be considered satisfactory. If 0.01 is the probability that a parachute will not open during a jump, such parachutes, of course, should not be used, but if 0.01 is the probability that a television set will require warranty repair, that consignment of televisions need not be rejected.

As a rule one of several mutually exclusive events must occur as a result of a test. Thus, when firing at a target which represents a circle 10 cm in diameter, deviation of the puncture from the center of the target may be less than 1 cm, from 1 to 2 cm, 2 to 3 cm and more. If the test result is characterized by a value related to deviation of the puncture from the center of the target, this value will vary from one shot to the next. We can determine this value, for example, using a scoring table (see Table 1).

TABLE 1

Events	Value of x (number of points)
Deviation of hole less than 1 cm	$x_1 = 10$
Deviation 1 to 2 cm	$x_2 = 9$
. . . .	. . . .
. . . .	. . . .
Deviation 9 to 10 cm	$x_9 = 1$
Miss -- deviation greater than 10 cm	$x_{10} = 0$

The values that characterize a certain test result and take on different values from test to test under, from our point of view, identical conditions, are called random values. In the example at hand random value X is the number of points scored with one shot.

The law of distribution is the most complete characteristic of a random value. It is usually said that the law of distribution of a random value is given if all of its possible values and the probability of each of them are listed.

In the general case, if a random value acquires different values $X_1, X_2, \ldots, X_n$ with probabilities $p_1, p_2, \ldots, p_n$, respectively, then the law of distribution is conveniently given in tabular form (Table 2).

TABLE 2

x	x_1	x_2	. . . .	x_n
p	p_1	p_2	. . . .	p_n

Here, obviously, $p_1 + p_2 + \ldots + p_n = 1$, i.e., in an individual test the random value will certainly acquire at least one of the listed values.

In the example of firing at a target the law of distribution of holes can also be expressed in tabular form in accordance with the preparation of the marksman. Thus, for the first marksman we will assume it to be of the form illustrated by Table 3. It is clear from the table that this marksman hits the "ten" an average of 16 times out of 100 shots, not less than the "eight" in 45 cases and misses with only 5% of his shots.

TABLE 3

x	10	9	8	7	6	5	4	3	2	1	0
p	0,16	0,15	0,14	0,12	0,11	0,09	0,07	0,05	0,04	0,02	0,05

The law of distribution of holes for the second marksman may differ substantially from that of the first (Table 4). Of course, it may turn out that we will contradict in this example what we stated at the beginning of the article: indeed the probability of miss of the first marksman is zero. Does this mean that he never misses? This contradiction is imaginary. First, we recorded the values of the probabilities only with a certain accuracy (in the given case, rounded off to hundredths), and secondly, in practice the law of distribution is derived on the basis of limited experimental data, on the basis of past observations and always with only a certain degree of accuracy. Therefore there is no guarantee that our marksman will never miss, even though he never has.

TABLE 4

x	10	9	8	7	6	5	4	3	2	1	0
p	[illegible]	[illegible]	[illegible]	0,12	0,0[illegible]	0,0[illegible]	0,0[illegible]	0,0[illegible]	0,00	0,00	0,00

Generally speaking, if the probability of an event is close to zero, this does not mean that the event can never occur.

If the law of distribution is known it is easy to find many useful characteristics of a random value. One of them is the mean value (mathematical expectation) of the random value. We will denote it through $\bar{X}$. According to the data in Table 2 this characteristic is determined as follows:

$$\bar{X} = X_1 p_1 + X_2 p_2 + \ldots + X_n p_n. \quad (1)$$

For the first marksman, in accordance with Table 3, we obtain $\bar{X}$ = = 10•0.16 + 9•0.15 + 8•0.14 + 7•0.12 + 6•0.11 + 5•0.09 + 4•0.07 + 3•0.05 + + 2•0.04 + 1•0.02 + 0•0.05 = 6.55.

This means that the first marksman makes 6.55 points with each shot or, in other words, an average of about 66 points with 10 shots. This is a poor score for a sportsman with a small caliber rifle; this is how beginners fire. The second marksman has a somewhat higher score. With the data in Table 4 we can calculate $\bar{X}$. We obtain 8.46. The result is that this marksman is much better prepared than the first.

Mean values and mean indices are widely used in the national economy and in the military. They characterize the average state, "center of gravity," either of a given object or process over a long period of time under changing conditions or of a system of many identical objects.

An important and frequently employed property of mean values is their additivity. This property means that if the sum of random values, the mean values of which are known, is taken as a new random value, the mean value of the new random value is equal to the sum of the mean values of the components. We use this property when we converted from the average number of points scored with one shot to the average sum of points made with 10 shots.

If, for example, we are required to calculate the average result $\bar{X}$ of our two marksmen, each of which fires 10 shots, we obtain:

$$\bar{X} = 10 \cdot 6.55 + 10 \cdot 8.46 \approx 150 \text{ points.}$$

We will call the two random values X and Y mutually independent, assuming that one of our two random values, having acquired some value, has no effect on the law of distribution of the second random value. Mutually independent random values have another important property: the average product of the random values is equal to the product of the average cofactors.

Let X and Y be the results of measurement of the sides of some rectangle, expressed in meters. Random values X and Y are independent, and their averages are $\bar{X}$ = 60 m and $\bar{Y}$ = 40 m, respectively. In this case the average area of the rectangle will be

$$60 \cdot 40 = 2{,}400 \text{ m}^2.$$

Also important in practice, in addition to the average value, are the characteristics of scattering of random values. As the very term implies, these indices give a measure of the spread, scattering of test results around the average value.

One of such characteristics is dispersion -- the mean square deviation of the random value from its average. If this characteristic is denoted through σ^2 then, on the basis of Table 2, it is defined as follows:

$$\sigma^2 = (X_1 - \bar{X})^2 p_1 + (X_2 - \bar{X})^2 p_2 + \ldots + (X_n - \bar{X})^2 p_n,$$

where $\bar{X}$ is calculated beforehand using equation (1).

The index σ^2 can be used in many practical problems as the criterion for determining the influence of random factors on an investigated process or phenomenon. Near-zero values of σ^2 mean that deviation from the average, especially substantial deviations, are improbable. In other words, the examined system is stable in relation to external action. If, for example, the discussion concerns the dimensions of parts manufactured on an assembly line, this signifies high production precision and stability of the manufacturing process. In the case, however, of large σ^2 there is considerable scattering of the results, and random factors have a very great influence on the system.

The introduction of additional concepts of the theory would involve unwieldy calculations and proofs. Therefore we will confine our discussion to the concepts that we have already examined above, supplementing the presentation with a few simple examples of the solution of specific problems. The first pertains to the problems of reliable striking of a target by small-arms fire.

Suppose that we are given the task of striking some target. Here we know that a strike is achieved with a single direct hit. We are required to obtain the result with a probability of 0.999. In other words, if we assume that such a problem would be solved repeatedly, then the task should be accomplished an average of 999 times out of 1,000.

We will further assume that each individual shot hits the target with a probability of 0.9. Clearly, a single shot is not sufficient for the solution of the stated problem. What, then, is the minimum number of shots that must be fired in order to attain the stated goal?

Assuming that the shots are fired independently, for instance, from various firing positions or by different marksmen, the problem can be solved quite easily.

We will assume that only one shot is fired from each position. Then, assuming that each shot hits the target with a probability of 0.9, we obtain: for repeated firing there will be an average of 900 hits and 100 misses out of 1,000 tries. If a second shot is always fired, then, in view of their independence, 90 of the 100 misses of the first firing will be hit. Thus, with two firings there will be only an average of 10 misses out of 1,000 shots. The result is quite high, but it still does not satisfy the stated requirements. Two shots are not enough.

We will make three shots in order to accomplish the mission. Now the third shot ensures an average of 9 hits of the 10 misses that remain after two shots (out of 1,000 tries). In other words, an average of 999 tries out of 1,000 are successful. This, then, means that the stated problem is solved. Thus the minimum expenditure of ammunition is three rounds.

We will take the second example from the realm of choosing an effective way of operating some material system. We will assume that we are working with an electronic system, let us say an electronic digital computer. And suppose there is some apparatus, malfunctioning of which disrupts the normal operation of the entire system.

Tests of the apparatus demonstrated that malfunctioning is associated with three types of disorders A, B and C. Out of 10 breakdowns of the apparatus an average of 7 are attributed to disorders A, 2 to disorders B and 1 to disorder C. It takes 5, 10 and 30 minutes, respectively, to correct disorders A, B and C. The malfunctioning apparatus may be replaced with a spare instead of correcting the disorder. This operation requires an average of 10 minutes.

What course of action should be taken in the operation of the complex?

If the average down time is used as the criterion, then in the first case, according to the relations presented above for determination of the mathematical expectation, we obtain the average down time $\overline{T}$:

$$\overline{T} = 0{,}7\cdot 5 + 0{,}2\cdot 10 + 0{,}1\cdot 30 = 8{,}5 \text{ minutes.}$$

Thus, it is better to correct the disorder. Here the average time gained during operation is 1.5 minutes per each case of breakdown. Moreover, there is no need for a spare component.

Mathematical statistics is an important branch of probability theory. It gives the rules for organizing experiments, processing and generalization of the results of tests, observations, measurements, recommendations on how to make decisions on the basis of limited information.

Suppose that we are required to determine the values of certain parameters that characterize a prototype weapon. This problem, clearly, can be solved only through the processing of the results of polygon tests. And here the methods of mathematical statistics are indispensable. With mathematical statistics, in particular, it is possible, on the basis of analysis of test data (called sampling) to obtain the approximate averages and dispersions of values, with which we became familiar when we discussed the basic concepts of probability theory.

Here is another example. Certain modifications are made in the design of an aircraft which, in the opinion of the designers, should improve some of the performance characteristics of the plane. Thereupon it is proposed that the modernized version undergo tests. We are required to determine the volume of tests, work out a test program and determine, on the basis of their results, whether or not the expected improvements were actually made. This type of problem is also examined in mathematical statistics.

During the process of mass production it is essential to exercise control over the fulfillment of technological requirements. The problem of control generates an enormous group of problems, the solution of which is possible through the application of statistical methods.

It should be mentioned in conclusion that human activity can be stripped to a considerable degree of randomness, with the result that goals will be attained more reliably and in shorter time. Before this can happen, however, the laws of random phenomena will have to be discovered and used. This is why the development of the methods of probability theory and their ever expanding application in science, technology and in military affairs are so important.

INFORMATION THEORY AND CONTROL OF TROOPS

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Before Making a Decision

The military reader is fully aware of how important it is to a commander to have timely information concerning the actions of the enemy, our own troops, the character of the terrain, supply of ammunition, and other supplies. It is for this reason that much of the work of headquarters is made up of the collection and analysis of the data that the commander must have in order to make a wise decision. And when the decision is reached, headquarters tries to transmit it to the executives so that each one will receive the required information on time.

During combat headquarters continuously controls the actions of the executives. It receives information, analyzes it and reports to the commander, permitting timely reaction to changes in the situation.

Under conditions that characterized the latter stages of the Second World War, the headquarters were able, though with difficulty, to cope with the processing of streams of incoming information. Indeed, the communications systems were often in a very complicated position: their transmission capacity satisfied, to some extent, the requirements when the headquarters were located at the site, but were completely inadequate in terms of movements and dynamics of combat. Now the situation is even more complicated. If in the past intelligence concerning the enemy was gathered basically by aerial photography and reconnaissance groups, and radio reconnaissance and radar augmented them, now the basic flow of information concerning the enemy comes from a combination of electronic monitoring systems.

The United States Army, for example, makes extensive use of pilotless planes, which can obtain information from ordinary on-board radar systems and side-looking radars, transmit signals of infrared detection systems, determine the presence of large metal masses magnetometrically. At the same time it can transmit to earth aerial photographs taken aboard the aircraft and, in some cases, television pictures of the situation. American spy satellites conduct aerial photography of the territory above which they fly and take thousands of pictures in just one revolution around the earth. They also transmit data from infrared detection systems, radio reconnaissance data, etc.

The ever expanding masses of intelligence information must be processed timely and forwarded to the commanders and appropriate headquarters in readable form. The use of nuclear missiles increases the flows of information even more. In war time it becomes necessary to collect, process and transmit data of the radiation situation, and the need for accurate weather information also increases sharply. The problem of determining topographical and geodesic characteristics of the region of combat actions is also complicated. The mobility and considerable dispersion of our troops necessitate greater speed and accuracy of the transmission of data concerning them.

It is obvious from the above that the control of troops is based on the continuous exchange of information and its processing, which consists in separation of the most important information and transmission of this information to the interested parties.

During combat actions under modern conditions the number of sources and consequently the number of flows of information in all chains of command have increased explosively, and the volume of information in the flows has also expanded. Consequently data transmission time has increased, which gives the enemy greater possibilities for creating interference. And if data processing time increases, the information ages and its value is diminished, and decisions are made late. The communication lines are often overloaded and the need for communications sytems increases. Military specialists, naturally, must find solutions for all these problems. And an important tool in this effort is cybernetics, or more precisely, a branch of cybernetics called "information theory."

With information theory it is possible to carry out quantitative analysis of flows of information and to determine its value. It is thereby possible to establish how essential a given flow is, determine its volume and intensity, distribute the flows of information in the best way, and to sort out the required and discard the superfluous information.

The term "information" is usually defined as any information concerning an event, phenomenon, system, object, their condition, actions or behavior. A flow of information is a certain quantity of information reaching its consumer from the source of information per unit of time via all existing communications lines between them.

In information theory a communication channel is defined as any means of connecting the source of information and its consumer, from live conversation between communicators to a radio channel, which transmits information over millions of kilometers from an interplanetary spaceship far from earth.

Information theory investigates the general principles of the transmission and processing of information, seeks out methods for its quantitative evaluation and reliable transmission via any channel. Born considerably earlier than cybernetics, as early as the early 1940's from practical problems of communications theory, this theory has become an extremely effective mathematical tool for analyzing various control processes.

Any control system has controlling and controlled objects. This may be, for instance, the headquarters and the unit commander subordinate to it, connected by means of communications channels. From the viewpoint of cybernetics the process of control consists in the exchange of information between these objects, its processing and conversion, issuance of command information by the controlling agent and of executive information by the controlled agent. Pertinent here are the storage, retrieval and readout of various reference information. In other words, any control process must be viewed first of all as an information process. Information theory also deals with the selection and guarantee of the best forms and methods of performing information processes. It concentrates its attention on the most important aspect of communication lines, namely the quantity of information that can be transmitted without distortions per unit of time. The physical processes that take place in communication lines are not discussed here.

Information theory does not examine, for instance, what a channel is. Information theory is indifferent to the method of transmitting information: whether only two people sitting in a room are carrying on conversation or there is radio communications between the earth and a spaceship.

The mathematical apparatus of the theory of information is the familiar theory of probabilities. Many new concepts, however, have been developed for the solution of its problems. Thus, information theory considers that the object (system), information concerning which is transmitted, may be in one of a number of states possible for it, and therefore a certain degree of indeterminancy is inherent to the object. On what does it depend? We will examine, by way of example, two systems with a different number of possible states.

The first system is a point target, at which a single shot is fired. From the point of view of information theory this means that the given system possesses two possible states. For simplicity we will assume that these states are equally possible.

It may be a high-alitude reconnaissance plane, a fighter plane, bomber, cruise missile or, finally, a transport plane. It develops that this system possesses five possible states. We will also assume here that all states are equally possible.

For which of these systems is it easier to predict the possible state? In other words, what is more easily established: what is the first target most likely to be -- destroyed or not, or of what type is the aircraft detected by radar most likely to be?

It can be shown by means of simple calculations that the indeterminancy of the second system under these conditions is two or more times greater than that of the first. This is understandable and reasonable. Since the second system has a larger number of states in which it may exist with equal probability, prediction of which of these states it will occupy in a specific case contains greater indeterminancy than prediction of one of the two possible states of the first system.

It can be shown by this example that the degree of indeterminancy of a system depends on the number of its possible states. Generally speaking, however, this is not altogether true. We will re-examine the same example, but under different conditions. Suppose the states of the second system (aircraft detected by radar) are not equally probable. We will assume that the probability of the first state is 0.9, that of the second is 0.09, third -- 0.009, fourth -- 0.0009 and fifth -- 0.0001. Using simple calculations it can be shown once again that the indeterminancy of the second system under these conditions is now approximately one-half that of the first system -- the point target at which a single shot was fired. In other words, the type of aircraft can now be predicted with greater certainty: it will almost certainly be a reconnaissance plane. Thus, the indeterminancy of the system depends not only on the number of its possible states, but also on their probabilities.

On the basis of the concept of degree of indeterminancy of a system the fundamental concept of the quantity of information that carries some information concerning the examined system is developed in information theory. The quantity of information is measured by decreasing the indeterminancy of this system after receipt of information.

Returning to our example, we will assume that along with information concerning the detection of an aircraft we receive information concerning its speed -- 1,000 km per hour and altitude -- 30,000 meters. These reports carry different quantities of information, since they affect differently the reduction of indeterminancy of the system. Actually indeterminancy consists in the lack of knowledge of the type of aircraft detected. The information concerning its velocity of 1,000 km per hour has practically no effect on indeterminancy, since according to foreign data, aircraft of all examined types can fly at such speed. It turns out that the information concerning the speed of the aircraft carries no quantity of information in this case.

Meanwhile the information concerning the altitude of the aircraft -- 30,000 meters -- satisfactorily characterizes the type of aircraft under certain conditions. We know that only individual types of aircraft can fly at such an altitude for any period of time. And so the information concerning flight altitude considerably facilitates the problem of determining the type of aircraft detected, facilitates the reduction of indeterminancy of the system. This means that the information carries a certain amount of information concerning the system. It is easy to see that the concept of the quantity of information is identical to the concept of its value.

These are some of the fundamental concepts of information theory. As in any higher mathematical discipline, they may turn out to be fruitless and barren. We have already learned, however, that with their aid we can obtain answers to important practical problems that cannot be solved by other methods.

Signals on the Way

The problems of information theory are employed in many branches of modern science, technology and the military. They have been most thoroughly developed, however, in application to the transmission of information via communications channels. Examined here are problems concerning the best coding, by which it is possible to transmit information using the least number of symbols in the absence and presence of "interference"; the problem of increasing the transmission capacity of communications channels: of improving the interference stability of transmitted reports. Some of the problems of information theory pertain to determination of the methods of input, storage and readout of information from the memory banks of computers.

Information theory may also render great assistance in the perfection of troop control methods. Indeed, the control of troops in combat or of operations is also an information process. Information in this case should be defined as the set of data used by the commander. Much of it is expressed in numerical form. These data, however, have different value. Thus, a report concerning the number of tanks in working order may not take into account the tanks that were put out of order during the time of transmission of the report to headquarters. Data concerning the coordinates of an enemy missile complex may differ from the true coordinates due to observation error and cartographic error, and may also be simply untrue, if the site is a decoy. The distortion of information transmitted in numerical form and intended for processing in a computer may lead to absolutely false results, even if the primary information itself was totally reliable.

The basic condition of troop control is knowledge of the situation and timely reaction to its change through development of the appropriate commands. The methods of information theory also permit selection of the most suitable forms and methods of transmission of information between the various administrative links.

Indeterminancy of the situation, as we know, has a substantial influence on the quality of troop management. It may be the result of the lack of sufficient quantity of information concerning friendly troops and hostile troops or its contradictory character. Certain changes are made in the decision to concentrate forces and equipment, to disperse them, etc., depending on the degree of indeterminancy of the situation. The indeterminancy of the situation and the value of the information are essentially component parts of strategic and tactical calculations. Information theory permits quantitative, i.e., numerical, analysis of the degree of indeterminancy of a situation and determination of the value of information which some report contains concerning the given situation.

Ye. S. Venttsel', in his book *Vvedeniye v Issledovaniye Operatsiy*

[Introduction to Operations Analysis], gives such an example. Four rockets were launched against a single target. The probability of target destruction by one rocket is 0.3. After the attack a reconnaissance aircraft is sent into the target area for the purpose of determining whether or not the target was destroyed. If it was destroyed then it is more difficult for the reconnaissance aircraft to spot it, and it is highly probable that it will bring back unreliable information. If, however, the target was not destroyed, reconnaissance easily detects it and more accurately determines its condition.

The reconnaissance aircraft does not bring any information concerning the state of the target. The probability of destruction or nondestruction of the target must be determined with consideration of reconnaissance results. If calculations essential for the solution of the problem are carried out, then it turns out that the probability that the target was destroyed was increased from 0.76 to 0.97, despite the fact that the reconnaissance aircraft did not bring back any information.

Organization of the optimal, i.e., most suitable, movement of information in all links of troop control is no less important a problem. Encountered here is a serious disadvantage of the data transmission system, namely its multistage character, which leads to delay of information and reduction of its importance. Therefore determination of the order of transmission in which the information immediately reaches its addressees is one of the most important areas of investigation in information theory.

The movement of information through the chain of command, its flows (direction, volume, intensity and form of transmission) are determined by the organization of control, composition of forces and the method of their combat deployment, and also the geographical environment. The volume of information in the flows can be reduced by decreasing superfluous reports. In fact, any language, including Russian, has superfluity. The so-called military language, despite its laconicity, is also superfluous to a considerable extent. Information theory proves that some of the words, conjunctions, prepositions, case endings and other grammatical forms can be omitted from a report without loss of comprehension. In the solution of this problem, of course, it should not be forgotten that superfluity also has a positive aspect, since it facilitates the process of reconstruction of a communication in the presence of interference-related distortions.

One way of reducing the superfluity of communications is to develop single tabular forms for oral and written information. This, however, requires detailed analysis of "military language" in order to reveal the most common words, expressions and grammatical forms. In other words, statistical analysis of military language, improvement of the terminology used in it are required. This will make it possible to "pack" an amount of information into fewer words, symbols and expressions without reducing the value of the information.

The problem of data transmission in communications systems is especially important in the military. Here information concerning the enemy, friendly troops and other required data enter the system in different forms, for instance as oral reports, written messages, signals on radar scopes. These reports should be transmitted via the communications channels and reduced as quickly as possible prior to transmission to the interested officers at headquarters.

In order to achieve such transmission the primary signals, i.e., the sounds of the human voice, symbols written on paper, light signals, etc., should be converted to electrical pulses. For this purpose the electrical current flowing through the circuit can be altered in some way or another so that its changes completely coincide with changes in the initial signal. In the simplest case it is possible, for instance, to send a direct current from a battery into a line in the form of short and long impulses -- "dots" or "dashes." The telegram, consisting of different combinations of such signals based on Morse code, is the simplest example of coding of a report, done specially to ensure its transmission over electrical communication lines. Each letter of the alphabet in teleprinter systems is coded by different combinations of uniform impulses and pauses. This five-valued code is called the Baudot code.

Information theory permits unique determination of which code is more suitable, more economical and how many times so under given conditions. The evaluation can be made according to various parameters, for instance from the viewpoint of ensuring the fastest possible transmission of a given communication, maximum interference stability, etc.

DC signals can be transmitted over wires or used to acuate a transmitter. In the latter case the impulses can be transmitted on one frequency and the pauses on another. At the receiving end of the communication line these two frequencies can be rectified and correspondingly converted into noncurrent and current impulses. Along the way, however, natural or man-made interference is inevitable superposed on them and the form of the signals will be distorted to some degree. Information theory, or more accurately one of its branches -- communications theory, makes it possible to find the most suitable means of coding, whereby communications can be transmitted with minimal distortion and by the speediest method.

Part of communications theory, called the theory of transmission of discrete communications, makes it possible to seek out methods of transmission and reception that ensure the required reliability of reception, increase the speed of transmission and reduce its cost. It should be pointed out that these problems are not solved individually or separately from each other, since each of them may be solved by means of another: speed can be increased by reducing reliability or something else can be increased, but at the expense of great sophistication and cost of the equipment.

American short-wave teleprinter systems, for instance, make extensive use of seven-digit codes. In these codes, of the entire set of possible combinations of pauses and pulses only those in which the ratio of the

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number of pulses and pauses in the code combination is maintained at four to three or three to four are used for coding the letters of the alphabet. During reception each combination is automatically checked and, if the prescribed ratio is not maintained, is recognized as distorted. Then the last three symbols are repeated. A special apparatus, which "remembers" the last three symbols of those transmitted, is used for this purpose. Constant feedback is required, of course, in order to achieve interrogation. This is easily provided, however, by duplex communications. As the result it is possible to elevate considerably the reliability of data transmission with substantial superfluity under conditions of moderate interference. Because of the inevitable repetitions, of course, the speed of transmission is reduced, and the system becomes unsuitable in the presence of strong interference.

Another example of an interference-proof code is the eight-digit code used in American systems of automated troop control. It uses only four combinations of impulses and pauses. During reception a check for parity is made and all odd combinations are recognized as distorted. Control is also exercised over the correctness of the received communication; the control sum of component digits is transmitted at the end of the report. If the control sum obtained does not coincide with that received, the entire communication is discarded and it is requested again.

Communications theory aids in finding ways to improve the reliability of transmission also without using feedback, although the structure of the codes here is greatly complicated. This theory also makes it possible to solve many other problems. Among them are determination of the transmission capacity of various channels under prescribed conditions, which makes it possible to compare transmission speed in real channels with their transmission capacity and to determine how efficiently they are used. Information theory is of particular importance in the development of methods of security classification of transmitted information, closely related to the solution of the principal problems of coding and decoding and ensuring stability.

It should be mentioned that all these problems were also important in the past, when the problems of communications systems were limited to the transmission of information in the form of telephonic or telegraphic reports. Now, however, with the introduction of electronic digital computers into the armed services, they are of crucial importance. The fact is that any automated control system has as its fundamental part a communications network that ensures circulation of information among the elements of the system. And since all the information is fed into computers in digital form, its reliability becomes a crucial factor. Therefore the methods of communications theory that permit design of systems that ensure a given reliability under certain conditions are of enormous importance. Information theory thus becomes a vital component of modern automated troop control systems.

It is clear from the above discussion that one of the most important problems of information theory is the selection of economical and efficient methods of coding information. The information, as it passes through the communications channels, is repeatedly transformed. These transformations are required for the coding of information, input of data into computers and display systems, readout from them and in many other cases. The transformation of information from one physical alphabet into another while retaining its sense and quantity is also called coding. Economical and efficient coding makes it possible to transmit information with the least number of symbols, which reduces the load on the communications channels, increases transmission speed and reduces the volume of data storage systems.

Economical and efficient coding also improves the interference stability of communications, and this is very important in troop control. The coding methods whereby errors in the transmitted reports can be found automatically are developed in information theory. The idea of such methods boils down to the fact that each transmitted symbol (letter, number) is accompanied by a conditional index, decoding of which permits detection of errors. Certain coding methods also permit not only automatic error detection, but correction of the errors without human participation.

The problems of ensuring the reception of signals, the level of which is substantially lower than the noise level, comprise a special field, the development of which is determined by the use of information theory methods. These problems arose primarily in the field of radar, where the target reflects a tiny fraction of the emitted signal, and this weak reflected signal must be received reliably. Successful radar beaming of the moon, Mars, Venus and other distant bodies became possible only after the methods of reception of weak signals, buried in noises, were developed on the basis of information theory. Communications with objects in space, for instance with a spaceship traveling toward Mars, or transmission of a television image from spaceships, transmission of photographs of the back side of the moon to the earth, would have been impossible without the basic concepts and practical conclusions of information theory.

We should also mention, finally, the perception of information. The dynamic nature and scope of modern combat actions may lead to a situation where there may be so much information, despite all measures to reduce the flows, that a commander cannot assimilate its content within the period of time available to him for controlling the troops. Here information theory can help in two ways. First, in determining the sufficient quantity and methods of displaying information on various display devices, such as screens, plotting boards, indicators, and second, in calculation of the number, scale and distribution of systems that graphically display a situation.

In addition to the above-mentioned military problems of information theory there are general problems that examine, for instance, calculation of communications lines and systems. Information theory is also extensively used in bionics, psychology and other fields of science and technology.

The development of military cybernetics and its introduction into the armed forces impose serious requirements on the level of technical preparedness of officers. Familiarity .ith information theory and its subsequent study are of the same importance under modern conditions as was the study of probability theory for artillery officers in its day. It should be mentioned that the mathematical apparatus employed in information theory corresponds to the level of high school programs, and therefore mastery of its methods should pose no serious difficulties.

WHAT IS THE THEORY OF SEARCH?

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The enemy must be discovered before he can be destroyed. Therefore observation and search are vital military actions.

The commander who organizes observation should make it as successful as possible at the minimum cost of men and material. Several questions arise in this connection: in which directions should the observation be conducted, what sectors are assigned to which observer, how effective will the observation be? Problems just as important as the above must also be solved during seeking out of the enemy, i.e., during observation involving movement and maneuvering of the observer. Here again arise the questions: which methods of maneuvering should be used by the forces conducting the search so that the enemy will not learn of detection, how should these forces be composed and organized, and how long is the search expected to last?

Even a short list of problems related to the organization of observation and search shows that it is impossible to solve them at first glance without serious analysis and calculations. The results of calculations on these problems must absolutely be expressed in quantitative form, i.e., in the form of specific numbers. Consequently the foundation on which the solution of the problems is based must be the "science of quantitative ratios and spatial forms of the real world" -- mathematics. In this case there is a general trend in the development of the military: transformation of military creativity into an exact science through mathematics.

As regards the problems of quantitative analysis of observation and search processes, they are combined into a special scientific discipline, which has come to be called in recent years "theory of search." The object of this theory is observation and search, regarded as random processes, the result of which is target detection. The methods employed in search theory, in fact, are general mathematical methods, primarily probability theory.

Direction of Observation

The principal task of search theory is to determine the best methods of observation and search on the basis of evaluation of their effectiveness. There are three principal component parts in search theory: kinematic fundamentals of search, target detection, and choice of optimal search method.

The fundamental principles of mutual motions of the observer and target (hence the term "kinematic principles") which lead to their convergence on the effective range of the observation systems, are examined in the first part. Contained herein are several important theoretical and practical conclusions, which should be examined by way of specific examples.

Suppose that an observer, in an aircraft, tank, or ship, is searching for fixed targets, which may be located on land or at sea in random fashion. These targets may be mines, a stricken ship, etc. In order to properly organize observation during search it is essential to know in what directions the target is most likely to appear in relation to the moving observer. Since the targets are located randomly in relation to the observer their appearance in different directions will obviously also be of a random character. Analysis of random processes, indeed, is the subject of probability theory, by means of which it is also possible to solve our problem.

With the methods of probability theory it is possible to calculate that the best effect in the given case is achieved by observing directly in the direction of travel, i.e., at an angle of zero degrees to the observer's heading. The worst result will be achieved by observing at any large angle. Thus, during observation at an angle of 45 degrees to the heading the probability of the appearance of the target in a narrow sector decreases 30%, and during observation at an angle of 90 degrees and more the target should not be expected to appear. The advisability of observing a head on course (hence the term "forward looking"), long used on ships, and which corresponds to the best conditions for conducting search, becomes obvious.

Further analysis of the search for fixed targets shows that if the observer scans a broad sector, the middle of this sector should be located in the direction of travel. For example, if the sector comprises 90 degrees and observation is conducted from 45 degrees port to 45 degrees starboard, the probability of spotting the target will be 70%. If, however, the observer begins to scan a sector of the same size, but observes from 45 degrees to 135 degrees port, the probability of spotting the target drops to 15%, i.e., is reduced by a factor of almost five.

The situation is more complex during search for moving targets, which is most important from the military standpoint, than during search for fixed targets. Search theory, nevertheless, has methods of solving this problem also. It is proven, in particular, that if the rate of travel of the observer is higher than that of the target the targets are most likely to be spotted ahead on course of the observer. It is improbable, however, that targets will be spotted in lateral directions and behind on course.

How to Spot a Target

The second part of search theory -- target detection -- examines the range of problems related to the efficiency of observation methods during search. The fact is that the appearance of a target within the limits of the expected effective range of the observation system does not necessarily mean that the target will be spotted. Detection may not occur for a number of reasons. Thus, the conditions of observation may differ from the normal conditions used in the calculation, which will lead to a reduction of the effective range of the observation system. This will happen, for instance, on ships using sonar equipment, the operation of which is affected by the hydrological situation, during visual observation from an aircraft or from a tank, which is dependent on optical visibility, and in other cases. The target may not be detected also due to poor preparation of the operator, due to improper functioning of the observation systems.

As we have seen, detection of a target as it appears within the zone of the expected range of the observation system, like the appearance itself, is a random event, and this means that it too obeys the laws of probability theory. The collection of factual information concerning the observation of targets under specific conditions is of enormous importance in establishing the probability dependences of detection on the various observation conditions. It is extremely important to know where, when and under what conditions a given target was spotted. The processing of this information by the methods of mathematical statistics and probability theory yields data for prediction of the expected probability of detection of a specific target and helps to determine the conditions under which detection is most reliable.

This branch of search theory also makes it possible to develop scientific recommendations for the preparation of observers, concerning their instruction on instruments and trainers, when all the essential observational skills are developed.

The third part of search theory pertains to substantiation of the most suitable methods of conducting search.

Consider this example. Suppose that a target was spotted at some particular point and then lost. There is no information concerning its direction of travel, but its speed is presumably known. The task of search in this case will be redetection of the target. What is the best way to lay out the courses for search in order to bring about the quickest possible detection of the target at minimum cost to the forces?

Search theory convincingly shows that the best course of travel for the observer in this case should be an ever expanding logarithmic spiral, or practically, in fact -- a broken line corresponding to it (see Figure 1). Here the origin of the path of the observer is located near where the target was first detected. This method, known as variable course search (or spiral search), was often used in the last war and produced good results.

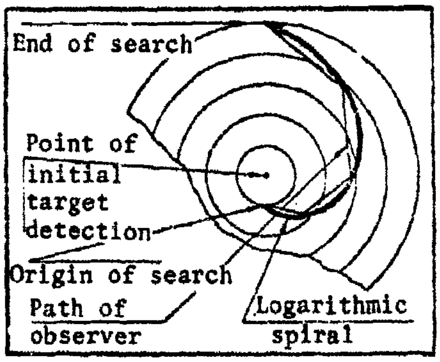

Figure 1. Search route.

Observer Automatons

The development of quantitative methods of analyzing military operations, including search, has yet another extremely important aspect: mathematization -- the key to automation of the control of military actions. The mathematical relations that have been obtained with the aid of search theory and other branches of cybernetics are becoming the foundation of programs by which operate computers which process information in short periods of time and perform calculations related to combat control.

As an example of an automaton designed on the basis of search theory, and which solves one of the important search problems -- determination of the character of a detected target, we cite the "Cybertron-100" system, information on which was published in the foreign press. This electronic device automatically compares the sonar echo reflected by an unknown marine target with a reference signal stored in its memory bank and corresponding to a submarine. Then the device prints out an answer concerning the character of the detected target.

It is noteworthy that the "Cybertron-100" trains itself to determine targets. For this purpose signals received from various targets, including those corresponding to submarines, are recorded on a special tape of the memory bank. The computer compares them and prints out an answer. If it is erroneous the instructor-operator presses a button and the computer repeats the comparison process. This process continues until the correct answer is obtained. The computer thus "trained," ensures rapid and correct recognition of submarines with an error not greater than that of the most experienced sonar operator.

Such are the fundamental concepts of one of the most interesting directions of the mathematization of the military -- search theory. It should be pointed out, however, that this theory is not limited in scope to the military. It is easy to see that it may also yield important results in the search for fish, whales, minerals, stricken ships and aicrafts and in many other practical cases.

MODEL OF COMBAT

Colonel-Engineer P. Tkachenko, Candidate of Technical Sciences

Model and modeling are words now commonly used by scientists and engineers. Before new hydroelectric power plants are erected the flow of the water in the old and new riverbeds, in the hydroengineering installations and turbines is studied on models. Models placed in a wind tunnel make it possible to establish ahead of time the behavior of aircraft designs in the various modes of flight. It would not be exaggerating to say that modeling is carried out to some degree or other in the development of every complex specimen of new technology. Thanks to the achievements of cybernetics the most complex processes in the fields of biology and physiology are beginning to be modeled.

What distinguishing features should models possess and how is the concept of modeling defined? A model is an object or process that reflects the basic features and principles of the development and behavior of an investigated object or process. There are scale (physical) and logic (mathematical) models. As implied by the name itself, a physical model is a material model, whereas a mathematical model represents a set of equations.

A model, of course, is poorer and simpler than nature, although with its help it is possible to conduct analyses that are not always possible and accessible on the real object. It often happens that full-scale investigations are complex, uneconomical, or lead to destruction of or damage to the investigated object.

Models have varying degrees of approximation to nature. The model that yields results with satisfactory accuracy at acceptable costs is usually selected. Evaluation of the accuracy of results is always one of the most important moments of modeling.

The very process of creating a model is sometimes called modeling, but incorrectly. Modeling is analysis of the behavior of real objects and processes on their physical and mathematical models. Modeling is based on a mathematical analogy, consisting in the fact that different physical processes are described by the same mathematical equations.

For example, such apparently different things as the oscillations of the leaf springs of an automobile, oscillations of the balance wheel of a watch, voltage oscillations in an electrical circuit and pressure oscillations in water lines are described by the very same mathematical equations. The operation of leaf springs or of a water supply system can therefore be analyzed on models of an electrical circuit or, as is often said, on electrical models. The converse may also be true: the behavior of electrical circuits can be analyzed on hydraulic models.

The following types of models are distinguished, depending on the choice of material medium: mechanical, hydraulic, pneumatic, electrical and thermal. Many of them have been used and are being used for the development of new types of weapons. Thus, a report appeared in the foreign press concerning the large-scale use of electrical modeling in the process of aerospace and radar design. Much of the data required for the building of new ships is obtained by means of electrical and hydraulic models. Modeling has also been used and is still being used quite extensively in the military. We know, for example, that prior to the siege of Izmail the troops of the great Russian general A. V. Suvorov used a model of the fortification walls. On this model they worked out the best siege tactics. During the Second World War, before the attack on the American naval base at Pearl Harbor, the Japanese constructed a model of this base with all fortifications in order to determine the best version of surprise attack.

Ordinary command headquarters training and military games can also be considered models of combat actions. Their distinction as models consists in the large number of conditions, insufficiently complete consideration of enemy counteractions and other limitations.

Training exercises conducted with troop participation have fewer conditions and produce much more data for evaluation of a given version of military actions. In this case too, however, enemy counteraction cannot be considered with the required completeness and accuracy. The important disadvantage of most training exercises is that they are conducted only once. Therefore their results can be random, and this means that they will be unsuitable for serious conclusions.

It should be emphasized that in the modeling of such complex events as combat actions it is impossible not to encounter an element of randomness. Despite the fact that their outcome is influenced by completely defined objective principles, these principles may manifest themselves in a random fashion in each individual battle or engagement. Only through the repetition of events under identical conditions will their average result be stable and independent of chance.

It has been established that stable average results can be obtained from a group of at least 12-16 random events. We also know that not a single course of instruction, for several reasons -- technical, economic, organizational -- can be conducted often enough to reveal all possible variants of interaction of conflicting sides of identical initial strength and grouping. At the same time it is obvious that to completely abandon modeling of combat actions in some form or another would be improper and ill-advised. How can this contradiction be resolved?

The answer is the use of the methods of mathematical modeling of combat actions of troops with the aid of computers. The number of operations in this direction has increased sharply abroad in recent years. Foreign military specialists feel that without mathematical modeling it is impossible to make serious and scientifically sound decisions concerning the makeup of the armed forces, methods of conducting combat actions and equipping them with military hardware.

Mathematical modeling is useful in the solution of the problems of combat application and evaluation of the effectiveness of weapons, development of the best means of carrying out combat actions, training and improving the qualifications of command personnel.

Sometimes all these problems are solved, as reported in the press, by means of a single model, and in some especially complex cases a special model is created for the solution of each problem. The foundation of the model is logic or mathematical description of combat actions, which in itself is a rather complex matter. Foreign works in this field indicate that the complete mathematical description of combat actions has by no means been achieved and will hardly be achieved in future years. The greatest successes abroad have been achieved through the use of mathematics for describing the combat actions of air defense, naval and aviation forces and systems.

The use of the method of mathematical modeling for analyzing combat actions of ground forces has not been as successful. The reason for this is the great diversity of ground forces, complexity and diversity of their actions and the need to consider terrain features. Only in recent years have mathematical works begun to appear in the foreign press concerning combat actions of artillery and tank forces.

The following order of development of the mathematical model is used in such works: statement of problem; choice of restrictions and determination of accuracy of model; formulation, i.e., mathematical description, of the process of combat actions and construction of algorithm; refinement of system of criteria required for evaluation of current and final results of modeling; evaluation of accuracy of results. The most complex stage of this work, as stated in the press, is formulation of the process of combat actions. In what does this consist?

Each engagement or battle is aimed to some extent at inflicting damage on the enemy. When little damage is inflicted on the enemy his resistance decreases. He is, as they say, "intimidated," but does not lose his capacity to conduct warfare. If damage is heavy, the enemy, in some form or another, terminates combat actions. The greatest degree of damage is total destruction of the enemy.

The initial strengths of the combatant sides and the rate of introduction of reserves, amount and quality of weapons, skill and political morale of the troops, preparation of command personnel, state of control systems, combat and material-technical support of the troops, condition of the rear, meteorological and topographic conditions all influence the result of combat actions. Some of these factors, as mentioned in the foreign press, do not yet submit to quantitative analysis, and their influence can be estimated only qualitatively. This is especially true of the morale factor.

Troops display high morale spirit in their stability and ability to carry out combat actions under severe conditions, for example with high casualties. Everyone knows intuitively that a few troops with high morale can achieve the same combat results as a large number of men with lower morale. No one will say, however, that a certain increase in morale stability (fighting spirit) of troops is equivalent to a reduction of their number by the same factor.

Despite the fact that there is no quantitative unit for measuring the fighting spirit of troops, its evaluation can be approached indirectly. It has been established from the experience of previous wars that troops, on the average, lose their ability to resist and become disorganized when their number drops below 60% of initial strength.

Troops with high morale do not lose their combat viability, even after sustaining a high percentage of casualties. There have been cases when the battle continued as long as there were soldiers capable of holding a weapon in their hands. This is particularly characteristic of wars of revolution and liberation.

The morale of the troops depends on such factors as the character and purpose of the war, social makeup of the army, level of education and discipline, bearing of command personnel, level of medical and material support of the troops, and duration of their participation in combat. It is no easy task to determine the influence of all these factors on the level of combat preparedness. Assumptions and restrictions are essential here.

Foreign specialists in mathematical modeling of combat actions either assign the relative strength factor corresponding to the loss of fighting ability, or assume this coefficient to be the same for both sides, which means that the modeling is done under the same conditions in relation to the morale of the troops participating in the combat.

The qualitative factors include also the level of troop training. It quite readily yields to quantitative evaluation. Well trained gunnery crews, for instance, accurately and quickly zero in on a target, which is manifested in the results and rate of fire, quantities that can be measured both objectively and quantitatively.

The most reliable source for quantitative evaluation of qualitative factors are statistical data obtained on special troop training exercises, firing drills or bombing exercises. Special groups are created abroad in such repetitive exercises for the purpose of recording and timing the actions of a large number of combat teams, crews, commands, and posts. The statistics thus accumulated are processed and used for objective evaluation of the combat readiness of troops and for mathematical modeling.

It should be pointed out that the quality of the weapons is a quantitative factor, despite its name. The quality of weapons is always manifested in quantitative characteristics: range and precision (scattering), area of destruction, rate of fire, velocity, protection (armor plate in the simplest case), reliability (malfunction ratio), service life. Consideration of these characteristics in the mathematical model is not especially difficult, since they are all expressed as numbers.

The construction of mathematical models of combat is a complex matter, but is, to a considerable extent, accessible to modern science. Modern science deals most successfully with the quantitative and digital evaluation of factors and processes which once were considered only qualitatively and purely superficially. Let us see just what are the results of mathematical modeling of combat.

Suppose that two sides, possessing a certain troop strength and known quantity of weapons, oppose each other. Let the quality of the weapons, morale of the troops and level of training of the personnel also be known. Each side strives for victory and tries to find the best means of action. In order to evaluate the results to which a certain course of actions of these conflicting sides may lead, we may use mathematical models.

In describing mathematically the process of combat actions, foreign specialists usually consider active means that have a direct impact on the enemy, and auxiliary means that support combat actions. The latter include communications systems, engineering and transport facilities, etc. Auxiliary and active systems have a certain bearing on each other and influence such numerical characteristics of combat actions as troop protection, rate of movement, transmission time of signals, and orders.

The active means may be in the following states: a) preparation for combat actions; b) observation (target search); c) delivery of fire power against the enemy (firing and bombardment); d) movement. Some of these states may coincide in time. The realization of each state obeys strict objective laws, including the laws of search, firing, and movement.

We will examine, for example, the process of observation. The quality of observation is characterized by the average number of targets detected per unit of time. This number depends, in turn, on the properties of the observation instruments, skill and training of the observers, types and sizes of targets, distances to them, terrain, and weather conditions. Certain objective relationships exist between all these values, which can be described by means of mathematical equations.

The distinguishing feature of these relations is that they are of a random, probability character, but this too can be considered by means of the appropriate equations. The concept of probability of target detection is used in the mathematical models. If the probability of target detection is 0.7, this means that the target can be detected in 7 out of 10 cases (or 70 out of 100 cases). The following mathematical expression of the law of target search is often used in approximate models: "The probability of target detection, assuming other conditions to be equal, is directly proportional to the visible target area and is inversely proportional to the square of target range." If we consider the "other conditions," then the mathematical expression of the law of target search, naturally, will be substantially more complex.

The laws of firing determine the relationship between target destruction probability and its size, type, range, firing accuracy, gunnery crew errors, etc. The laws of movement establish the relationship between the probability of selection of some rate of travel and the condition of the soil, character of the terrain, degree of fire effect and other factors.

All these laws are used in mathematical models for determining the probable results of combat actions. The most thoroughly developed models of conflict abroad are those for like systems -- aircraft with aircraft, artillery with artillery and tanks with tanks. The development of models of combat between unlike systems, as reported in the foreign press, is still fraught with serious difficulties related to evaluation of the equivalence of these systems and their importance or danger for the opposing sides.

Mathematical models of combat actions are categorized in the foreign press in two large classes. In the first class of models the effect of each factor on the result of modeling can be traced to the end with the aid of equations. These models are usually quite coarse and the results of modeling are represented graphically. The change in the strenghts of the sides are plotted as a function of the duration of combat actions. Such models are often called analytical models.

The simplest examples of analytical models are the Lanchester models, named after their author, the English clergyman and mathematician, who started to analyze combat actions after the First World War. We will consider an example of a Lanchester model of combat actions for the case of a fire fight between combatant sides[1].

We will assume that side "A" currently has n_a combat units that can go into action against the enemy. The other side "B" at the same time has n_b active combat units. Suppose the firing speeds of the combat units, measured by the number of shots per minute, are c_a and c_b, respectively. The weapons employed by each unit have destruction radii r_a and r_b. Hence the areas of destruction of the weapons of side "A" will be $S_a = \pi r_a^2$, and the areas of destruction of side "B" will be $S_b = \pi r_b^2$. We may assume that

[1]This example was developed by P. N. Tkachenko.

any combat unit of the other side that enters the limits of these areas will be destroyed if a sufficient number of shots is fired.

To characterize the protection of the combat units we introduce the concept of damaged areas. The less an object is fortified, the greater will be its damaged area and conversely. The damaged areas can be regarded as circles without introducing significant errors and the concept of radii of destruction R_a and R_b can be applied.

Now all we have to do is consider the quality of firing with hit factor α, which characterizes the average ratio of shots that hit the target. We may now proceed to formulation of the equations. They should help us in determining how the strengths of the conflicting sides change in time.

We calculate, for example, how the strength of side "A" changes during a short period of time Δt. During time Δt side "B," acting against side "A," fires $n_b c_b \Delta t$ shots. Some of these shots, equal to $\alpha n_b c_b \Delta t$, hit the target. What is the average damage inflicted on side "A" by the on-target shots?

We will first examine one target and one weapon (Figure 2).

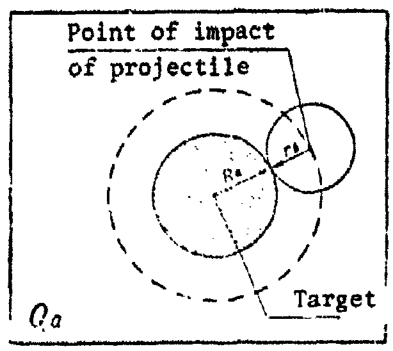

Figure 2. Target and projectile.

If the target is located in area Q_a and has radius of destruction R_a, then it will be destroyed if the point of impact falls in a circle of radius $R_a + r_b$. The probability of striking the target will be equal here to the ratio $\pi(R_a + R_b)^2 : Q_a$. If in the same area Q_a are located n_a targets, then the probability of hitting one of them is greater and will be

$$\frac{n_a \pi (R_a + r_b)^2}{Q_a}.$$

We can see in the expression obtained the fraction of all combat units of side "A" damaged by a single shot of side "B." Since the number of shots required for destruction of the target is K_a, the total number Δn_a of combat casualties of side "A" during time Δt will be

$$\Delta n_a = \frac{n_a \pi (R_a + r_b)^2}{K_a Q_a} \cdot \alpha_b n_b c_b \Delta t.$$

By analogy we obtain for side "B"

$$\Delta n_b = \frac{n_b \pi (R_b + r_a)^2}{K_b Q_b} \cdot \alpha_a n_a c_a \Delta t.$$

We will introduce the following definitions:

$$\varkappa_a = \frac{\pi (R_c + r_b)^2 \alpha_b c_b}{K_a Q_a};$$
$$\varkappa_b = \frac{\pi (R_b + r_a)^2 \alpha_a c_a}{K_b Q_b}.$$

These will be the values that characterize the combat properties of the conflicting sides. We will them the effectiveness factors. Striving now for $\Delta t \to 0$, within the limit we obtain

$$\frac{dn_a}{dt} = \varkappa_a n_a n_b;$$
$$\frac{dn_b}{dt} = \varkappa_b n_a n_b.$$

Division of one equation by the other convincingly shows that the losses of one side in the given case is a linear function of the losses of the other. Indeed

$$\frac{dn_a}{\varkappa_a} = \frac{dn_b}{\varkappa_b}.$$

Consequently

$$\frac{n_a}{\varkappa_a} = \frac{n_b}{\varkappa_b} + C,$$

where the constant C is determined by the initial conditions. Denoting the initial strengths of the sides through n_{a_0} and n_{b_0}, respectively, we obtain

$$n_b = n_{b_0} - \frac{\varkappa_b}{\varkappa_a}(n_{a_0} - n_a). \qquad (1)$$

We introduce to the examination the relative strengths of the sides:

$$\varphi_a = \frac{n_a}{n_{a_0}} \quad \text{and} \quad \varphi_b = \frac{n_b}{n_{b_0}},$$

whereupon equation (1) acquires the form:

$$\varphi_b = 1 - \frac{\varkappa_b \cdot n_{a_0}}{\varkappa_a \cdot n_{b_0}} (1 - \varphi_a). \tag{2}$$

The graph of this function is illustrated in Figure 3. Point D corresponds to the beginning of combat actions. The relative strengths of the opposing sides are equal to one, and the absolute strengths are equal to the initial strengths. During the course of combat the strengths of the sides begin to diminish. How long will the battle last? Obviously, until one of the sides retreats from the battle, acknowledges defeat or is wiped out.

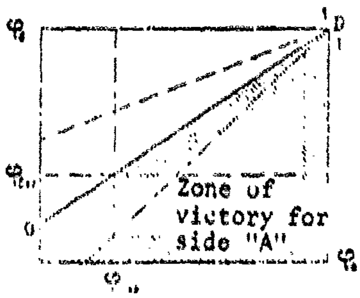

Figure 3. Reduction of strengths of conflicting sides.

Actions usually do not continue to total annihilation of both sides on a large scale, since at some critical relative strength $\phi_{a\ cr}$ or $\phi_{b\ cr}$ one of the sides loses its capacity to resist because after suffering heavy casualties the troops become demoralized, panic and cease to be controllable. Obviously, the critical relative strength depends on the steadfastness of the troops and their fighting quality. On the average we may assume $\phi_{cr} = 0.4\text{-}0.6$.

If the conflict develops so that the relative strength of the sides change according to line OD, this means that both sides have the same strength and the conflict will cease when both sides simultaneously reach the critical casualties point. Substituting the values $\phi_{a\ cr}$ and $\phi_{b\ cr}$ into equation (2) we obtain the condition of equality of the forces of conflicting sides or, speaking in the language of chess, the condition of stalemate:

$$\frac{\varkappa_b n_{a_0}}{\varkappa_a n_{b_0}} = \frac{1 - \varphi_{b\,cr}}{1 - \varphi_{a\,cr}}, \quad (3)$$

Hence it follows that numerical equality is by no means sufficient for conflicting sides to achieve actual equality. There must be a certain relationship with respect to the quality of weapons (effectiveness coefficients κ_a, κ_b) and with respect to troop stability coefficients ($\phi_{a\ cr}$, $\phi_{b\ cr}$). Therefore equation (3) should be regarded as a criterion of victory by which it is possible to establish certain numerical relationships between the qualitative and quantitative factors that influence the result of military actions. Nothing can be said of the effect of these factors on the outcome of combat without consideration of the numerical relationships between these factors. One can only speak of the need to consider certain qualitative factors, as most authors have done up until now.

Suppose, for example, that side "A" has $\phi_{a\ cr} = 0.5$ and side "B" has $\phi_{b\ cr} = 0.4$. In other words side "B" is stronger than side "A." In this case side "A," assuming it has weapons of equal quality as side "B" ($\kappa_a = \kappa_b$), in order to achieve actual strength equality must increase its initial numerical strength by 20% or think of the corresponding improvement of weapons quality, for example by increasing the radius of destruction (r_a), firing quality coefficient (α_a) or by improving the protection of its troops (R_a). The choice of a given variant should depend on the specific conditions.

An example can be taken from the history of the Russo-Japanese War of 1904-1905, when the conflict proceeded approximately in accordance with line OD in Figure 3. This was the battle of Liaoyuan. The Russian troops (side "A") had high initial numerical strength, but poor-quality weapons, which somewhat offset their higher fighting spirit, so that condition (3) was, on the average, satisfied. Both sides sustained great losses until both commanders nearly simultaneously ordered the troops to withdraw from occupied positions. The Russian commander in chief Kuropatkin, it is true, issued the command somewhat earlier, approximately a half hour as established later. This enabled the Japanese to notice the retreat of the Russian troops and to return to the abandoned positions.

It is easy to obtain from equation (3) the condition of victory of side "A." For this purpose, obviously, it is necessary that the line of change of relative strength pass above the "stalemate" line. This will occur when

$$\frac{\varkappa_b n_{a_0}}{\varkappa_a n_{b_0}} > \frac{1 - \varphi_{b\,cr}}{1 - \varphi_{a\,cr}},$$

which can also be regarded as the condition of victory for side "A." In order for side "B" to win the inequality sign should be changed to the other side.

There can be many variants of mutual distribution of the graphs of conflicting sides' strength, depending on specific conditions. Their analysis makes it possible to establish the effect of the investigated factors on the outcome of military actions. The U.S. Army checked certain standard indices of the Field Service Regulations in approximately this manner. They confirmed, in particular, the field manual premise that in order to achieve stable victory in man to man combat, in which both sides are equally armed, the initial numerical superiority must be at least three to one.

In another class of models the result is usually represented in the form of a diagram. The characteristic feature of these models is that here the relations that do not yield to analysis with the aid of mathematical equations are replaced by logic conditions. These conditions are realized in computers according to certain rules with the aid of the so-called random numbers sensor.

Suppose the computer has to choose the direction of travel of a tank that has encountered an obstacle. If the conditions on both sides of the obstacle are the same, then the tank can get around the obstacle on the left or right with the same probability, equal to 0.5. If, however, the ground is soft to the right of the obstacle or there is danger of encountering fire on the flank, then the probability of getting around the obstacle on the left increases. By examining in this manner all possible states of combat units participating in conflict and considering the probabilities of these states, the computer traces step by step the events and their random relations incorporated in the model.

As a result of such modeling the computer prints out in prescribed intervals of time the coordinates of the combat units on the battlefield, their state, numerical strength and other values, depending on the purposes of the modeling. Figure 4, taken from the journal *Operayshens Riseorch* shows (according to modeling results) the paths of two medium tanks -- No. 2 and No. 9, lagging behind a company toward the end of an assault on a fortified position defended by 10 light tanks and 5 guns, 2 of which are shown in the figure. Toward the end of the given random battle the defenders still have 3 tanks and 2 guns. The positions of the sides were displayed every minute on a screen with a coordinate grid. Thus it was possible to trace how the tanks maneuvered, when they opened fire and the results of the firing.

Diagrams were displayed on the screen for each combat unit participating in the battle. The model of the battle was played by the computer for 3 min, which is the equivalent of 30 min of actual combat. Modeling was carried out between 50 and 100 times and then the average stable number of losses was calculated. The described model was used in the United States for choosing the best tactics of actions of tank units and for preparing tank company commanders. In the latter case the rate of the modeling was artificially slowed down.

One of the important aspects of modeling is evaluation of the accuracy of the results obtained. In other words, within what limits and to what degree can the results of modeling be relied upon. It is known that the best criterion of theory is practice. To subject a theoretical model of combat actions to a thorough practical check, however, is not possible. Therefore a partial check, the method of historical analogies or experimental studies are used abroad for evaluating the accuracy of models.

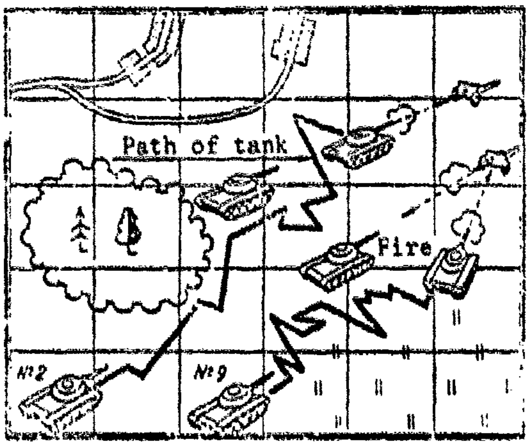

Figure 4. Model of tank attack.

A partial check consists in comparison of the basic units of models, for instance the search and firing units, with actual setups. It is assumed that if the model is accurate in its basic units and the relations among the units are determined correctly, then the results of the modeling will be reliable.

Another method of checking -- historical analogies -- is based on modeling of past wars, battles or engagements, the results of which are exactly known. Comparison of theoretical results with the actual results makes it possible to determine the accuracy of modeling. It is important here that the compared results be sufficient in number.

Finally, special experimental studies are organized for checking of models. The U.S. Army has created at the Aberdeen Proving Grounds for these purposes an experimental tank regiment, which conducts repeated studies with simulated battle firing and accurate recording of its results. Variously colored lead projectiles are fired from the tank guns. On striking armor they leave spots, on the basis of which the time and results of the firing are determined.

It should be stated by way of conclusion that the use of mathematical modeling as a whole may turn out to be extremely beneficial in many cases. In particular it may lead to important results in the solution of the problems of troop control. The use of modeling in military affairs is the outgrowth of the rapid development of cybernetics. It heralds the continued penetration of mathematics into military science.

THEORY OF CONFLICTING SITUATIONS

Major-Engineer M. Goryainov

Two companies of a regiment, coming upon two enemy positions, make contact with them. The regimental commander knows that a decise victory can be achieved only if his forces have a superiority of at least two to one. He has learned from intelligence reports that the enemy has five companies, his regiment is one company larger, but has seen much action and is badly battered. Carefully thinking through and weighing the situation, the commander decides that the outcome of battle will be favorable under these conditions if the enemy losses are maximized and his own losses are minimized. The question arises: how best to use the remaining four companies that have not yet engaged in combat?

The only thing that can help the commander in this case is to remember that the enemy is in just as serious a situation, and that he is also considering how to distribute the forces among his positions. Two of his companies, one at each strong point, are presently holding off two advancing companies. But what comes next and how should the remaining forces be deployed?

Consider now another, not tactical but purely routine problem.

Imagine that you are walking along a riverbank with your fishing rod. The features of the river are such that its predominant population -- perch and roach -- do not tolerate each other. And so if perch are found in one place there will be practically no roach. However, you do not like the meat of one of the species of fish.

And so you decide to proceed along the bank, casting one time at each of your favorite places. As your bait you have bread and minnows. According to your past experience there are many fish here. True, they are small -- the perch weigh an average of 100 grams, and the roach 150 grams, but they bite readily. You bait your hooks and cast; you get a nibble but the fish won't take the bait. True, the bait situation is bad; perch do not go for bread at all, while roach won't take minnows. Your time is limited, and if you waste it on checking each fishing spot, then you will either catch few fish or be late getting home, and then you may miss dinner. Naturally, you would like to know in which order to cast the bait in each new spot.

If one analyzes both the above problems, then one finds that they have one thing in common -- conflict in the examined situation. In the first example the conflict is more obvious, but even in the second example it is there -- you are competing with nature: you may change your bait and move from one place to another, but nature "alternates" the roach and perch in an arbitrary but to you unknown order.

The solutions of these and many other similar problems are the subject of a comparatively new mathematical discipline -- theory of conflicting situations. It is also called mathematical theory of games. The content of games theory consists in analysis of conflicting situations -- those phenomena when the participants o' a situation, of which there must be at least two, strive for opposite goals. In this article we will examine only some of such phenomena, for which the theory is best developed. These are the so-called paired antagonistic games with the null sum. The problem with which games theory deals is to seek out the optimal, i.e., the best under conditions of conflict, course of actions for achieving the goal with the least risk.

The name "games theory" and many of the terms associated with it were coined historically. The reason for this is that games, especially games of chance, have much in common with all conflicts and readily submit to description and analysis. In the discussion that follows, to stress the difference between mathematical theory of games and, for instance, military games, we will simply call it the theory of conflicting situations. We will not, however, change the rest of the terminology.

The participants of any conflict, called "players" always pursue mutually opposing goals. This means that any increase in the gain of one of them is accompanied by a reduction of the gain of the other. The attitudes of the players are determined, in addition to opposition of interests, by the fact that certain elements that have a direct bearing on the payoff depend entirely on the choice of each of the players, i.e., are under their control.

There are, in addition, other elements which are beyond the control of the players, let us say the effectiveness of their available means of action against the challenger or the situation that exists prior to the conflict. These elements are considered hostile to neither player. An important factor is the state of information or intelligence, in other words the completeness of knowledge of the condition and intentions of the other side. Conflicting situations are divided on the basis of this criterion into situations with complete and incomplete information.

Situations are defined as pair, when there are two players and plural situations, depending on the number of players participating in the conflict.

Plural situations are much more complex than pair situations and are less developed from the theoretical point of view. It should be borne in mind, however, that since the players during the development of a conflict can form various "coalitions" -- temporary alliances of two or more players, characterized by the sameness of purpose, plural situations can often be regarded as pair situations.

The conflicting situations examined in theory differ from real situations in that they obey strict rules. In theoretical examination, therefore, proceeding from analysis of a phenomenon, a strictly defined system of conditions limiting the possible variants of actions of both sides, volume of information and sequence of moves are selected. Such a system of conditions determines also the results of moves -- the "payment" for each of them. A move here is defined as an individual decision made during the process of conflict. Moves can be personal, when they are deliberately chosen from a number of possible moves, and random, determined by means of some mechanism of random selection, drawing of lots for example.

The choice of a given move and the sequence of moves are determined by the players' "strategy." It must be said that this term has a somewhat different meaning in the theory of conflicting situations from that in military science. Here strategy means an exhaustive plan, i.e., one that completely defines the choice of a player's personal move as a function of the developing situation.

The decision to undertake some action is usually made during the course of development of the conflict. Under the rules mentioned above, however, a decision can be made ahead of time by analyzing different situations that can arise during the course of conflict. This, of course, is not easy, at any rate for a considerable number of conflicts, but theoretically is completely possible. Mathematical and physical models of processes can be extremely useful here.

And so, even if only theoretically, a player can construct and write a system of decisions ahead of time. This system of decisions, reflecting to some degree a player's intentions, will also be his strategy. And search for the best strategies is the domain of the theory of conflicting situations.

It is especially essential to emphasize the following point: in seeking out the best strategy it is assumed that the enemy is at least as intelligent as you, and that he will use all his forces to prevent you from winning. Therefore the result of the optimal strategy is what you may be able to gain in the developing situation by proceeding intelligently and at the same time very carefully.

It is now time to introduce the concept of "cost" and "payment." Payment is defined as a number by means of which is evaluated the benefit of the situation that exists as a consequence of the conflict. The quality of a given strategy is determined on the basis of analysis of payments. In other words, the payment is the measure of success of a certain action.

The problem of determining or setting the cost is rather complex and, generally speaking, extends beyond the realm of the theory of conflicting situations. We will simply point out that it is often necessary in practice to examine conflicts, the results of which cannot be evaluated in physical units, such as in units of energy or in rubles. In these cases it is necessary to use relative units of measurement. Their essence consists in the fact that by examining all possible results of a conflict the investigator assigns a certain "weight" to them. This weight depends on how much better and more useful is one result, in the investigator's opinion, than another. The accuracy of such an evaluation depends, of course, on the experience of the investigator and on how completely he has analyzed the problem. If in fact there are during the course of conflict not only personal but random moves, the evaluation of the gain may be its mean value or mathematical expectation.

We will now look at a few examples of the statement and analysis of problems of the theory of conflicting situations.

A company commander of the "reds," knowing that the enemy, the "blues," is preparing a tank strike against him, can use three types of antitank weapons: A_1, A_2, A_3. He knows that the "blues" have two types of tanks: B_1 and B_2. He also knows that the probabilities of destruction of tanks by each of the antitank weapons differ and equal, respectively: for weapon A_1 -- 0.8 and 0.6; for A_2 -- 0.3 and 0.5; for A_3 -- 0.7 and 0.3. The "red" commander is at a disadvantage in that he must request antitank weapons without knowing with what kind of tanks he will be attacked (this will be learned only during the process of battle). Moreover, only a strictly limited number of weapons is available to him.

Such a situation is a conflict with two personal (choice of tank and type of weapon) and one random move (tank destruction). The gain of the "reds" can be set equal to one in the case of destruction of all tanks and zero if they remain intact. The "reds'" strategies consist in the choice of type of weapon, and the "blues'" in the choice of the type of tanks. The average gain or payment for each pair of strategies in the given case will be the mathematical expectation of the number of damaged tanks. It should also be pointed out that this situation is one of the category of situations with incomplete information.

For analytical convenience we will enter, as is done in the theory of conflicting situations, the "payments" in the so-called "payment matrix," where each payment is entered opposite the corresponding pair of strategies (see Figure 5).

We will start the solution of the problem by analyzing the strategies of the "reds." If they decide on strategy A_1, then in the worst case for them -- blue strategy B_2 -- they can count on damaging 60% of all tanks. We turn our attention specifically on the worst variant, since the "reds" are faced with a clever enemy, who will also analyze the situation and can always respond in a way that is not in his best interest.

		Blue strat.	
		B_1	B_2
Red strat.	A_1	0.8	0.6
	A_2	0.3	0.5
	A_3	0.7	0.3

Figure 5. Matrix to tactical problem.

		Nature	
		Perch	Roach
Angler	Min.	100	0
	Br.	0	150

Figure 6. Matrix that could be devised by angler.

If we also evaluate the other two "red" strategies we will see that the worst outcome there will be 30 and 30% damaged tanks. Obviously, the best result that the "reds" can count on, even under the worst conditions, is 60%, which by and large is not so bad.

The "blues" are extremely interested in a different problem: what actions to take in order to minimize losses, even under the worst conditions. Analyzing his strategies from this perspective the commander can see that if he uses the type B_2 tank he will lose not more than 60% of his tanks, even in the worst case ("red" strategy A_1). This result, of course, is not so good. In the other two cases ("red" strategies A_2 and A_3) the position of the "blues" is considerably improved -- 50 and 30% losses, respectively.

Thus the solution of the problem amounts to the following: the "red" commander should use the weapons of the first type, i.e., strategy A_1. In this case "blue" tank losses will be at least 60%, no matter what type of tank they use. Thus if the "blues" use the B_1 tank the "reds" will increase the percentage of tanks that they can knock out to 80%. No mixture of tanks that the "blues" can deploy will improve their situation, because in this case their tank losses will fall somewhere between 80 and 60%.

Only one strategy remains for the "blues," and it is obviously B_2.

The solution for which both players have singular optimal strategies, as in our case, is called the solution in pure strategies. We will note that the one which after several repetitions provides the player the maximum possible average gain is called the optimal strategy.

The solution of the fisherman's problem will be somewhat different. This situation represents a conflict with one personal and one random move. The gain, naturally, is defined as the number of fish that can be expected to be caught. Our strategies consist in the choice of bait, and the "strategies" of nature in alternation of the perch and roach at the places where we will be fishing.

We write the conditions of the problem also in the form of a "payment matrix" (see Figure 6) and try to find the solution in pure strategies. We will use our first strategy -- minnows. Each time we find a spot where perch reside a minnow, according to the condition, will give us a 100-gram fish. But imagine the following unfortunate case: we always stop at a place with roach, and then according to the same condition we will catch nothing. The same thing is also true of our second strategy -- fishing with bread. We are faced with the following question: is there any way that we can alternate our bait so as to be better prepared for any "trickery" of nature?

The theory of conflicting situations gives for the above-examined problem a simple practical rule for determining the strategies at our disposal and the frequency of using them. On the first row of the payment matrix we should subtract the second row and, ignoring the sign, assume the result to be the frequency of use of the strategy. Here, for the first strategy, this will be the result of substracting the second boxes, and for the second -- the first boxes.

In our case the result of subraction will be 150 for the first strategy and 100 for the second. It is not very convenient, however, to use these figures. Therefore we will divide each number by 250 -- let this be the total number of casts. As a result we obtain 3/5 and 2/5. These figures mean that to reach the best result it is necessary in 3/5 of all cases to use our first strategy (minnows) and in 2/5 the second (bread).

This solution is called solution in compound strategies. This means that the optimal course of actions will be the use, in a certain proportion or with a certain frequency, of some of the pure strategies at the disposal of the player.

It is interesting that the fishing problem, with different initial conditions, can have a completely different sense. For example, bait can be substituted by various types of fighter aircraft ammunition, and fish by types of enemy bombers. The "payment" in this case will be completely different -- the expected percentage of destroyed bombers of one type or another.

It is easy to see that in those cases when the solution is found in compound strategies it is necessary to take certain measures to prevent the enemy from discovery the order in which pure strategies are used. Otherwise he will be able to respond to each pure strategy with his own optimal strategy. To prevent this, a specific pure strategy is selected in random fashion (by drawing lots), but is used with the frequencies obtained in the solution.

The gain from each of the strategies is called the "score" of the game. In our example with the choice of antitank weapons it was rather easy to calculate: it is equal to the result of using strategies A_1 and B_2. In the example of the fisherman, however, it is a little more complex.

Theory states that here the game score for our compound strategy will be the result of adding the products of the frequency of use of the first strategy by the payment of the left box of the first row of the matrix and the frequency of use of the second strategy by the payment of the left box of the second row. Hence the game score averages 60 grams. The score for optimal strategies is the gain that is maximum if the enemy makes no mistakes.

This statement is not hard to prove, even by the example which we gave at the very beginning of this article. The regimental commander's problem, of course, is more complex than those we analyzed in detail. Therefore we will discuss only the response and those interested in learning a method of solving the problem are referred to the special literature, where the so-called "Blotto" type situations are discussed.

By the conditions of our problem the payment is equal to the number of defeated enemy companies minus our own losses. Then the optimal strategy of the regimental commander will be to order the remaining four companies to one or the other of the enemy strongholds. This also involves solution in compound strategies, where the frequency of use of individual pure strategies is 8/9 and 1/9 in favor of either stronghold.

It should be pointed out in conclusion that the theory of conflicting situations is not yet completely developed and methods have been worked out for the solution of by no means all types of problems. Nevertheless its fundamental postulates are completely rigorous and even now it may be very useful in the analysis of certain conflicting situations encountered in practice. This usefulness consists in seeking out and substantiating decisions that are optimal in terms of the prescribed conditions of conflict and "price." In the simple examples which we examined above we could obviously find the solutions intuitively. Only by means of theory, however, is it possible to prove these solutions. In real life, moreover, where there are the most conflicts, there intuition is hardly useful and the right escape from a situation is by no means obvious. We will demonstrate this in a very real example, taken from the history of World War II and examined by the American researcher Heywood.

During the New Guinea campaign the U.S. Army command found out that the Japanese intended to send a large convoy with troops and supplies from the port of Rabaul on the east coast of New Britain Island to the port of Lae, New Guinea (see Figure 7). This convoy could pass either to the north of New Britain, where there would almost certainly be poor visibility, or to the south, where clear weather was expected. The voyage would take three days in either case. General Kenney, commander of the American forces could concentrate the main forces of his reconnaissance planes either on the first or second route. After the convoy was discovered it could be bombed before arriving at Lae.

General Kenney's headquarters determined in the days left for bombing the various results of reconnaissance decisions. When portrayed on a payment matrix (see Figure 8) it is easy to see that the optimal strategy for

General Kenney will be the one corresponding to the northern route. Actually, in any case he would have had two days for bombing, whereas in the case of the second strategy (southern route) there was a real risk of having only one day for bombing.

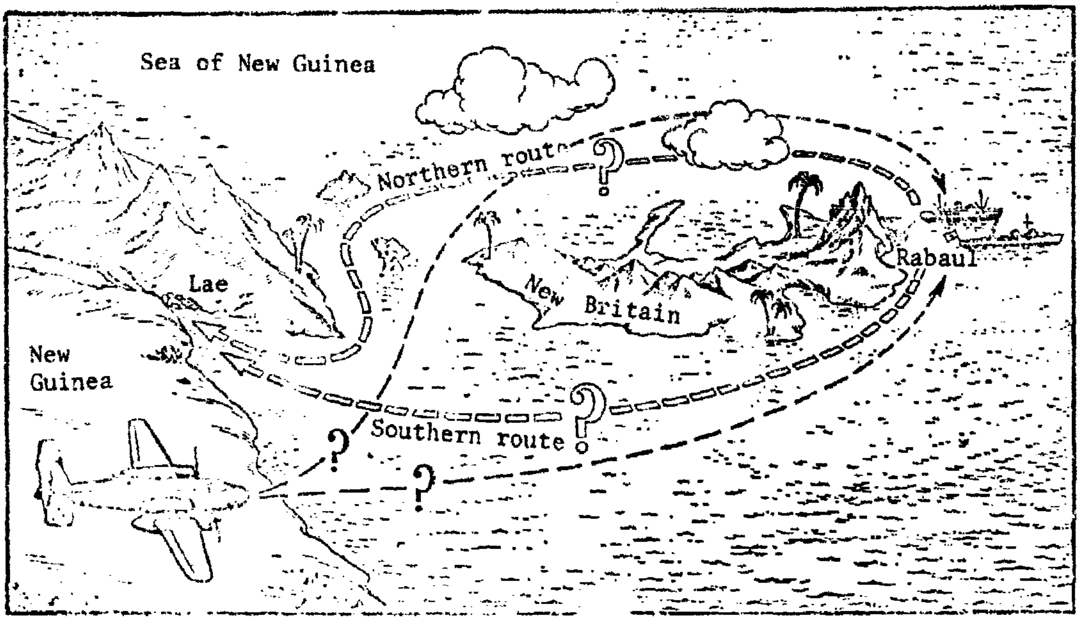

Figure 7. What route to take?

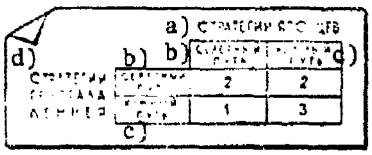

Figure 8. Choice of optimal strategy.
Key: a, Japanese strategies; b, northern route; c, southern route; d, General Kenney's strategies.

This was the strategy used. The Japanese convoy was spotted on the northern route one day after going to sea. For two days it was attacked by bombers and sustained heavy losses. It is noteworthy that the situation turned out very badly for the Japanese, since neither the first nor the second route was favorable for them. It is true that the choice of the northern route, which is the one that they selected, offered, in the event of an error on the part of the Americans, the hope of being bombed for only one day.

The following question might be asked. is not the abstraction involved in the construction of a mathematical model of conflict too great? This may be answered as follows. There are many abstract models that are of considerable benefit. Take, for instance, the wind tunnel, in which the aerodynamic properties of aircraft are analyzed. Here only average, generalized conditions are reproduced with great success. Still, it is simply impossible to recreate all the different air streams that flow around an aircraft in flight.

Another example of useful abstraction is Newton's theory of gravity, which assumes the mass of each heavenly body to be concentrated at one point. This, of course, is not so but by using such a theory we can predict the motion of planets with sufficient reliability. This is why there is nothing surprising in the fact that by using an "abstract" model of conflict and selecting the optimal compound strategies for casting the trawl, the specializing mathematician can help the fisherman on a trawler to catch 20% more fish than other trawlers of the fishing fleet catching sea pearch in the Atlantic Ocean. Such examples can presently be found in newspapers and journals.

It is noteworthy that not long ago the name of the theory -- games theory, found unexpected direct verification. As reported in the United States and Soviet press, Doctor Edward U. Thorp, professor of mathematics of the University of New Mexico, developed optimal strategies for various situations of the American variation of the card game Twenty-one. As Professor Thorp states, he cannot lose. Moreover, if the game is played honestly he cannot help but win! And win he does. Bearing in mind his occupation (the professor teaches a course of functional analysis at the university) and the cheating of the card bankers, the average winnings are several tens of thousands of dollars annually. True, Doctor Thorp first had to analyze 34 million different card distributions (and consequently the same numb of different "moves") and without a large electronic computer, which the mathematician used, this problem could scarcely be solved. Analysis of all possible moves prompted him to work out several rather simple strategies and to win, as we already mentioned, if the game is played honestly. Indeed cheating in the given case is the same thing as violation of the familiar strict rules by which a conflicting situation must develop.

This example is yet another illustration of the attitudes of the capitalist world: a professor amuses himself during off-duty hours by picking the pockets of card bankers and proprietors of gambling dens. However, the mathematical problem which Thorp has solved is of unquestionable importance and is yet another step on the path of analysis of complex conflicting situations.

The range of possible application of the theory of conflicting situations is extremely broad, especially in the military. Its successful application requires only further development and perfection of solution methods. This does not mean, of course, that the theory of conflicting situations is in any way contrary to tactics and professional creativity. On the contrary it enhances them substantially by expanding the possibilities of analysis of military actions. The theory of conflicting situations may become a good assistant to the commander, but the final decision is always his.

THE COMPUTER AT THE COMMAND POST

Colonel V. Sinyak, Assistant Professor, Candidate of Military Sciences

Military specialists of all countries wholeheartedly agree that contemporary war will take place at a fast pace and will be exceptionally mobile in character. Enormous amounts of military equipment will participate in it. The events in such a war should unfold very rapidly.

Proceeding on this basis, many foreign authors point out the difficulties of controlling troops in contemporary combat. In their opinion headquarters will begin, for instance, to receive so much information concerning military actions that they will not be able to process it in time. It takes 2-3 hours for a commander to prepare data for decision making, even the most experienced headquarters officers of the division level. And during this time much can change on the battlefield. It cannot even be excluded that late information will not help a commander make the right decision.

How, indeed, under the new conditions, is it possible to influence the course of combat? Obviously it is necessary to have certain new technical means capable of solving the problem of troop control in a shorter period than people. But to say this is to say very little. It is essential to determine what specific processes of troop control submit to automation and what, despite the desire of people, as they are privileged to have, is beyond the ability of computers. The answers to these questions will be found by cybernetics -- the science that analyzes problems of control and communications in living organisms, machines and society.

Developing the theory of cybernetics, scientists noticed a great similarity between the process of control and the transmission of signals in technical systems, living organisms and in society. Any control as a process must occur in a closed cycle. In it participate the controlled and the controlling agents. They are connected to each other, on the one hand, by the control loop and on the other by the feedback loop. Command signals are sent over the control loop and how the controlled object reacts to them is checked on the feedback loop.

Foreign specialists, examining the process of troop control from this admittedly extremely simple point of view, point out that a high ranking commander is the controlling agent and a subordinate is the controlled agent. The control signals in this case are the instructions and orders of the senior commander. Here too there is a feedback loop. The fact is that well-organized troop control is inconceivable if the senior commander does not have the capability personally, through his headquarters or other means, of controlling the actual state of the controlled troops and how they execute their orders. Therefore the senior commander continuously receives reports concerning troop actions and their execution of orders. The latter is also the same thing as the transmission of information through the feedback loop (see Figure 9).

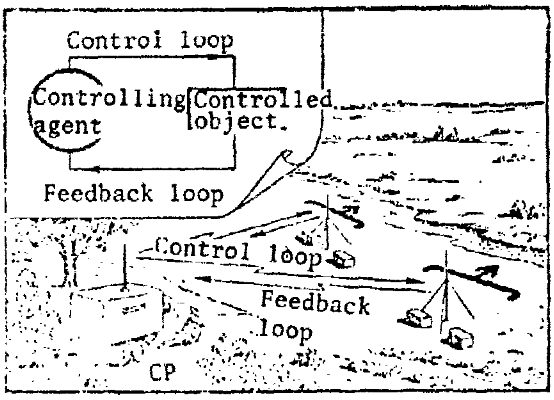

Figure 9. Feedback in combat.

Thus the control of troops is accomplished in a closed cycle, much like the control of various forms of equipment. The control of an antiaircraft missile, for instance, is accomplished by commands sent from a computer. The computer produces these commands after receiving information from the radar system that determines the coordinates of the target and missile. Here too there are a control loop and a feedback loop. But then the question arises: can not the process of troop control as a whole be delegated to some technical system, let us say an electronic computer? To answer this we will examine what human functions in the control of a missile are assigned to a computer. As we see, they are only the calculation of coordinates and the transmission of commands, i.e., the technical process, not related to creative work.

We will have exactly the same situation if we include an electronic computer in the closed cycle of troop control. Here of course it will operate by a somewhat different program -- man will prepare for it the initial data and read the results of its operation. But even in this case the computer can handle only the technical aspect of the job. The abilities of the "controlling" organ to think, create, to possess will and character, which are absolutely essential in troop management, are privileged to man. He and only he is capable of these. A computer, included in the control cycle, is capable of performing only the purely mechanical functions of man. However, even this limited use of computers in the control of troops, as pointed out by foreign specialists, can be of enormous benefit.

Actually, the work of the commander and headquarters specialists in troop control consists of two processes: creative and, so to speak, mechanical operations according to certain rules. Creative activity consists primarily in making a decision to go to battle and controlling it. Here, however, the commander evaluates the capabilities of the enemy and of his own troops, both qualitatively and quantitatively. Qualitative evaluation of troops is a creative process, during the course of which it is necessary to consider such factors as morale and class composition of the troops, their fatigue, training, combat experience, attitudes toward the enemy and toward war as a whole, nationality, endurance, courage, etc. Here, in fact, the foreign literature includes the leadership capabilities of the commanders, their combat experience, military training, personal qualities. As regards quantitative evaluation of troops, it includes determination of the grouping of troops, ratio of forces, supply needs and many other calculations.

Under various conditions of combat activity the commander and headquarters are also ocuppied with another laborious and at times monotonous operation. Take, for example, the coding and decoding of information, graphic display of situations on a map for clearer depiction of troop positions, various calculations, carried out by certain rules, developed long ago, and the writing of every possible type of report. This is all essential, but requires much time, of which there is little in combat. This is the type of activity, like quantitative evaluation of volumes of initial data for command decisions, that can possibly be automated partially or completely with the aid of electronic computers.

In reaching this conclusion, however, foreign writers stress the need to substantiate the reasonable limits of computer application in the control of troops. It does not follow at all from the above-mentioned similarity between the troop control process and any other control process that the improvement of the work of the commander and headquarters in combat will require in all cases the use of electronic computers. It has been put in print that platoon, company, battalion and even regimental commanders can easily exercise control with personal observation of the battlefield as their feedback loop. That is a different matter if we are discussing indirect control -- through a series of subordinate departments, as is done, for instance, in military large units.

Here, in view of the mobile character of modern warfare, there is a greater possibility of distortion of control signals and information signals in intermediate departments, which greatly increases the time of transmission of information from top to bottom and from bottom to top. It has also been stated in the press that during control of large units and joint forces the flow of information becomes so overwhelming that it is often difficult to generalize it and present it to the commander in readable form. Many foreign authors consider that the solution of this problem already demands the inclusion in the closed cycle of large unit and joint forces control cycle high-speed equipment permitting in extremely short periods of time, measured in seconds and in minutes at most, analysis of information and transmission of reports from the lowest to the highest echelons.

The control plan is not very different in the given case from that of closed cycle general control. The only difference is that the control loops are doubled up, since some of the information passes "through man," and the rest through the computer. In this case a high-speed electronic computer processes most of the information.

This is the way American military specialists envision this process. Information from subordinates of some department concerning the position and condition of the troops is fed via the feedback loop directly into a computer. The computer processes by the prescribed program and prints out for the commander and headquarters this information in generalized form, thereby performing, instead of the headquarters, laborious operations of quantitative evaluation of the troops, collection and processing of reports, etc. It may happen as a result of data processing that some control signal is developed, for instance an air raid signal. Then the computer instantly transmits it to the troops via the communication lines to which it is hooked up.

Nevertheless the chief function of troop control -- decision making, remains with the commander, even despite the fact that with the computer the commander will receive only a small part of the information (in the form of telephone conversations, written reports and personal reports).

It is not difficult to see, however, that the fruition of such ideas requires not only a computer, but also a special system which feeds the required information into the computer in a form suitable for immediate processing. In the opinion of foreign specialists such a "troop control system" should include a vast network of electronic systems: various means of detecting the enemy and determining the directions of future attacks; a system enabling the commander to obtain data concerning the air situation and the capabilities of available air power; communications system for transmission of information concerning friendly troops and reconnaissance data and, finally, electronic intelligence and jamming systems, the purpose of which is to collect information concerning the enemy by monitoring the operation of his electronics and disruption of the operation of these systems by interference.

Figure 10 illustrates an example of an electronic system for the control of a division. Its center is the data processing station (3), located at the command post, where the commander and staff officers work. The heart of the equipment of the station is a computer. It is connected to the primary data processing systems (2), located in all military elements of the division, at the command posts and headquarters of neighboring units and at posts in the rear. Also hooked up with these systems may be technical intelligence systems (1) -- radar, television cameras, infrared instruments, aircraft reconnaissance system, etc. The principle of operation of the primary data processing systems depends on the character of the information that must be transmitted by them to the computer of the processing center, and also on the arrangement of the system in the zone of action of the military units at the front or in the rear. The data themselves may be visual, transmitted via television, radar signals or oral reports. Teleprinter systems, similar to teletype, but operating at a higher speed, can be used according to the foreign press for text transmissions. Phototelegraphic instruments, which receive and transmit diagrams, tables, maps and other graphic data, can also be used.

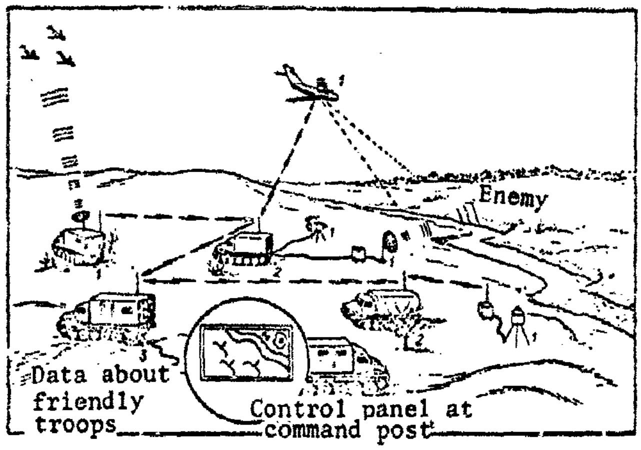

Figure 10. Electronic troop control system.

The computer installed at the processing center can store data in the form of recordings on magnetic tape in enormous volumes -- exceeding 25 million numbers or symbols. Here its printout mechanism can, in the course of a minute, retrieve from these recordings any information required by the commander, and the arithmetic unit automatically performs arithmetic operations at a speed of up to several tens of thousands of operations per second.

How should the data prepared at the sites for computer use be transmitted to the data processing center? Does the data processing center require a special communications system with equipment at all the sites? A definite opinion is found in the foreign press concerning this subject: there is no need for such a special system. The operation of the division computer system should be based on the usual division communication system. The electronic control system, with the aid of the intelligence system, computers, etc., will collect, process and analyze data concerning the enemy, concerning our troops and other information; the communications system will transmit this information to the processing center and to other points as required.

The information received by the processing center and processed by the computer should arrive at the control panel located at the division's front command post. Here, in various forms -- on television and radar screens, special situation maps, diagrams, etc., the picture of the situation on the battlefield will constantly be reflected. It is postulated, in particular, that continuous observation of the enemy will make it possible to supply the control system with sufficient data to graphically display the location and movement of enemy units and elements and to accurately determine their rate of travel, numerical strength and other required data.

The data assembled by the electronic control system will also enable headquarters personnel to rapidly construct, with the aid of the computer, an extremely detailed diagram of the region of military actions. On this diagram can be entered the boundary lines of the units, parts of the terrain that should be covered by scouting patrols, defensive installations and other elements of the situation. The picture thus obtained can, in turn, be rapidly transmitted via the communications system to the unit headquarters of the division, to the corps and army headquarters.

Foreign specialists working on the development of computerized control systems feel that such systems can render enormous assistance to commanders both in offensive and defensive warfare. It is emphasized in the foreign press that systems capable of speedy automatic generalization of data transmitted from ordinary and remote controlled aircraft, equipped for aerophotography, with television and radar systems, will greatly simplify, for instance, control of the quality of the equipment of defensive positions of their troops, will help to reveal deficiencies in their selection and concealment in a short period of time.

It is quite clear that the data processing centers of division electronic systems may be hooked up by communications lines to other such centers located great distances apart. Thus it will be possible to build a larger system of mutually connected centers, for instance army electronic control system and the system of the entire theater of military actions. As reported in the foreign press, the same equipment can be used for organizing the army system as for divisional systems, but capable of processing and transmitting considerably larger quantities of data. The electronic system of a military actions theater should incorporate even more powerful and sophisticated equipment, adapated for performing an enormous volume of operations on the "memorizing," processing and transmission of every conceivable type of data to army computer systems and higher headquarters. It is stated in the press that this computer system can be used not only for troop control on the battlefield, but also for the planning of war and military operations.

Thus, a number of foreign specialists propose that prior to planning army operations the army headquarters must assemble with the aid of the computer system enormous volumes of data concerning the enemy, region of military actions, terrain and climatic conditions, possibility of paratroop drops and other problems. On the basis of analyses of these data several sample courses of military actions can be put together. These variants should then be "played" on special computers, into which are fed alternately the elements of the variants and the possible enemy responses. All of this, of course, cannot be the final criterion for evaluation of the ultimate decision, since the choice of plan of operations will depend in the final analysis on acquiring the most accurate and complete information about the enemy and his actions. However, considering the work that has been done with the aid of the computer and many other factors, such as troop morale, the quality of their preparation, etc. -- it is easier for the commander to make a decision and he can to a large extent be hopeful of a positive outcome of the steps taken.

With the army and division computer systems it will be much easier and quicker to transmit military problems to the commanders and headquarters of all large units, units and services in the theater of military actions. Furthermore the army commanders, by virtue of the fact that the computer system that serves them is tied to the various organs and services of all the armed forces, can request the required information and rapidly obtain information concerning various problems. All army services, in turn, can acquire via the theater control system the information they need for planning operations, accounting and procurement. The transmission of requests from one computer system to another (for instance from the division to the army), according to foreign specialists, should be accomplished by mobile high-speed switchboards operating without human interference and capable of automatically connecting any components of individual computer systems.

Foreign specialists examining the problems of automation of troop control, not subjected to the ideas of the notorious theory of pushbutton warfare, make the following conclusion: the computer can never completely replace man in troop control. However it can lighten his burden enormously. By helping the commander and headquarters personnel to control subordinate units and subunits, the computer will make it possible to act in accordance with the requirements of modern warfare.

AUTOMATION COMES TO HEADQUARTERS

Colonel-Engineer P. Tkachenko, Candidate of Technical Sciences

Recent years have witnessed an intensive adoption of mechanization and automation in the sphere of administration and management. There is a good reason for this. The complexity and laborious nature of management processes compel a constant search for means to improve human labor productivity. The problem is to perform all management operations in shorter time, with fewer forces and with higher quality compared to the way it has been done in the past.

This fact is printed in the foreign press. In the United States it takes 21 men working in accounting, planning, control, preparation and issuance of instructions for every 100 men directly involved with industry. It has been calculated that if the management methods used 50 years ago were used today, then there would be at least 40-50 people working in administrative and managerial positions for the same 100 workers. Thus the trend is toward reduction of the apparatus with improvement of management quality. This is the essence of the adoption of mechanization and automation.

Troop control has much in common with industrial management or agricultural management. Under military conditions, however, it is much more complex. The situation on the battlefield changes rapidly, which cannot be said of industry, which operates under comparatively stable conditions. Moreover, enemy counteractions, casualties and loss of equipment are strongly reflected in decisions that are made and in the control process generally.

All military problems that have to be solved by the commander and headquarters during preparation for and waging of war can, from the mathematical point of view, be divided into computational, data and logic problems. The computational problems include determination of strength ratio, calculation of requirements for various materials, etc. These problems are characterized by comparatively small volume of initial data, given in the form of various numbers, on which are performed large numbers of arithmetic operations. In information problems, on the contrary, comparatively few arithmetic operations are carried out on a very large number of initial data, such as reports concerning the makeup, condition and supply of the armed forces.

In contrast to the first two types of problems, logic problems are characterized by the fact that during the process of their solution it is necessary to consider factors that are not only quantitative, i.e., denoted by numbers, but also qualitative, ' pressed not by numbers, but by words such as "greater than," "less than," "better than," "worse than," "yes," "no." This means that when solving a logic problem the commander seeks an answer to the question of the best way to act in a given specific case: let us say what route to take, how to make up a military formation, the best locations for firing positions, etc.

The correct and speedy solution of problems related to troop control during the period of preparation of combat actions and during the course of these actions has always demanded of the commanders good special preparation, training and high character qualities. Now, however, when new and improved equipment is being used on the battlefield, these problems become even more complex and the periods of time in which they must be solved are becoming shorter and shorter. A unique contradiction arises between the capacities of the commanders, headquarters and requirements on the organization of troop control.

In light of the above statements the increasing interest displayed in the armies of the US and other countries in control problems becomes understandable. Analyses of control processes are carried out in three directions: determination of deficiencies in headquarters operations, development of new control methods using the so-called operations analysis theory and development of new control systems. As pointed out in the press in all recent exercises of NATO armies, especially in operation "Checkmate" (chess) the work of the armed forces headquarters was subjected to special analysis. Following one of the exercises a former chief of communications forces of the U.S. Army, Lt.-General O'Connell, declared that it is now impossible to control troops simply with the aid of telephone equipment and personal communications with subordinates.

What means of mechanization and automation of the reception and transmission of data are presently used or will be used in the near future? Can the ordinary telephone or radio station be included among the means of mechanization? Foreign specialists answer yes to this question. Before the invention of wire communications correspondence was delivered, as we know, by messengers on foot or on horseback. The invention of the telegraph and telephone replaced the labor of the messengers, accelerated and improved the transmission of oral and written correspondence. The adoption of the radio aided transmission of oral and written communications without having to string wires over great distances. Then the appearance of transmitters and teleprinters, which automatically receive and transmit information (certain transmitters can transmit text at the rates of 300 and 600 symbols per minute) boosted mechanization to a high level. Thus communications specialists are justifiably considered the first mechanizers of control processes in the armed forces.

The question arises: what are means of mechanization? How do we distinguish them from other means used by man in various forms of activity? Unquestionably, any technical device that facilitates, improves or replaces physical labor performed by man can be called a means of mechanization of manual labor. Specialists note, however, that the means of mechanization should not be confused with, on the one hand, instruments that improve or complement the capacities of human sensory organs (binoculars, theodolites, tape measures, voltmeters, etc.) and, on the other hand, with the tools of labor (drafting instruments, various special rulers and templates).

The highest degree of mechanization, indeed, is considered to be automation. These are the technical means by which not only physical but also mental work performed by man is improved, supplemented or partially replaced. The advance of automation into the realm of mental labor is one of the characteristic features of automation. Devices that improve the reliability of transmission by using various mathematical codes that detect and correct errors are also means of automation.

The means of mechanization used at headquarters, as mentioned in the press, are subdivided into three groups: low, medium, and high mechanization. Low mechanization includes mechanical or electric adding machines and desk calculators, which cut calculation time in half. Means of low mechanization of computational operations are used extensively in artillery and aviation unit headquarters, in topographic service offices and material and technical supply departments.

The means of medium mechanization of calculation operations usually consist of key-responsive adding machines that perform, in addition to simple arithmetic operations, an entire series of special operations such as automatic line replacement and printing of results. As seen from press reports, such devices are not used in the armed forces headquarters, but they do find rather extensive application in rear offices, especially in the finance service, construction organizations, warehouses and rations offices.

Means of high mechanization of calculation operations are punch card machines. These machines are usually employed in sets which include several interacting units. Their purpose is to prepare and process thin paper cards on which numbers are printed, in the form of holes (perforations), with which the required calculations are performed. A set of punch card machines is used when it takes several dozen men to carry out ordinary calculation operations. In such cases labor productivity is increased 3-4 fold, the number of accounting workers is reduced 2-3 fold and the volume of documents is reduced 30-50%.

According to statements in the foreign press, means of high mechanization are used basically in offices of the U.S. Department of Defense and at large headquarters. True, several years ago the papers printed that an attempt was made to use a set of punch card machines at an infantry division headquarters for processing intelligence information. Field tests showed that the load of the set did not exceed 40%, in which connection the use of these systems in division headquarters was considered inadvisable. At larger headquarters, for instance at field army headquarters, the load on the set was considerably higher, and its use there is completely justified.

A set of punch card machines usually consists of the following equipment: perforator, verifying key punch, sorter and tabulator. The purpose of the perforator is to prepared punched cards, the verifier checks correctness of their perforations, the sorter rapidly, at a rate of about 1,000 punch cards per minute, takes out the required data and the tabulator performs various arithmetic operations on these data and prints out the results. The general view of certain units of a set built by the Czechoslovakian firm "Aritma" is illustrated in Figures 11-13. These machines feature high quality, are equipped with a letter-number alphabet and are comparatively small, which enables them to be installed in vehicles and used under field conditions.

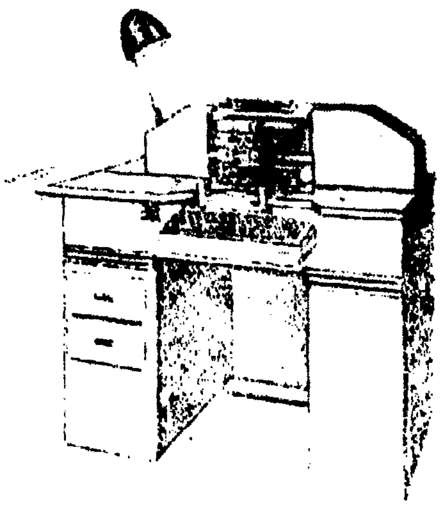

Figure 11. Letter-number perforator.

The use of punch card equipment in headquarters was the stage preparatory to the adoption of electronic digital computers, which are now the basic means of automation of troop control processes. Foreign specialists, however, cling to the opinion that computers by no means preclude the use of mechanization equipment in headquarters work. If the most difficult calculation problems of a unit or large unit are solved satisfactorily with the aid of the means of low or medium mechanization, then it is not necessary to use computers for this purpose.

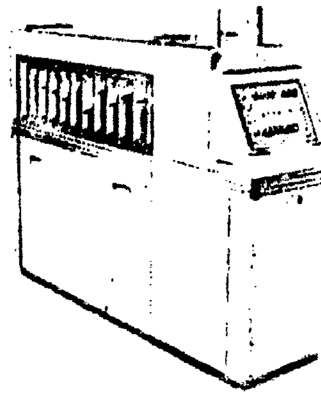

Figure 12. Letter-number sorter.

Nevertheless a lot of attention has been devoted abroad in recent years to the development of electronic digital computers and their adoption by the military.

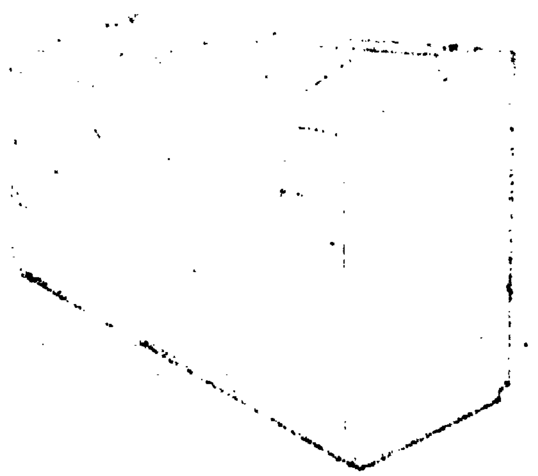

Figure 13. Letter-number tabulator with multiplication attachment.

A few years ago the building of electronic data and computer systems was the most prosperous branch of U.S. industry. The number of companies building computers mushroomed. Therefore the number of computers developed by the various companies, possessing about the same capabilities, became quite large. Computers for military application occupy a special position among them.

The U.S. Department of Defense has a great demand for this type of equipment. The military wheelers and iealers, heated by feverish preparation for aggressive war, successfully distribute orders among the firms producing computer equipment.

As pointed out in the foreign press, there has long been a need in the U.S. for special electronic computers in the air force and air defense. In recent years it has been supplemented by an attempt to use computers in infantry headquarters for automation of the processing of military information and for the solution of calculation problems. The introduction of electronic computers to the headquarters was stimulated by new types of armament, such as nuclear missiles, increased dynamicity of combat actions and the increasing importance of the time factor. The indispensable requirements on such computers are small dimensions, capability of installation on trucks or helicopters, high operational reliability under field conditions. In this connection military computers should be built on semiconductor elements, which have small dimensions and low sensitivity to mechanical and climatic influences. Development of such miniaturized, portable and highly reliable computers for the army was also a new boon to the American companies producing radio electronic equipment.

Efforts to automate troop control in the U.S. Army are conducted basically at the radio electronic equipment proving grounds in the foothills of the Huachuca Mountains in Arizona. Baldwin, the military correspondent of the *New York Times*, visiting Fort Huachuca, wrote that this proving ground is the largest scientific research organization of the U.S. Army. The personnel employed there are 5,200 officers and military engineers and 2,000 civilian specialists.

A computer center, equipped with large electronic computers of the type IBM-709, was displayed at the proving grounds in 1959. From the moment of organization until 1957 project "Sage," an automated air defense system, was developed at the proving ground jointly with the University of Massachusetts, which was then submitted to industrial firms for building by contract with the Defense Department. It is here, in fact, that light computers, designed for use under field conditions, have been developed since 1957. On the basis of these operations, remarked Baldwin, commander of the proving ground Brigadier General Murmen considers that in time the battlefield will be so automated that "thinking" machines will supply to the commander all information on technical, data and other problems that are required in a specific situation.

A special sector, consisting of several departments, was established at the proving grounds for research in the area of field electronic computers. By the end of 1958 its coworkers undertook an experimental project of an automated data processing system for troop control, called project "Fieldata." This system is based on computers connected together by communication lines.

The "Fieldata" system, as stated by the journal *Electronics*, includes the following components: "Moby Dick," "Mobilogic," "Logicpack" and "Basic Pack." The U.S. Department of Defense, after completion of the projects, signed contracts for the completed experimental specimens. Thus, the Sylvania Corporation was awarded the contract to build "Moby Dick." In the words of the journal *Communication of ASM*, development of the "Moby Dick" prototype was concluded in December 1959. This computer is a semi-conductor version of such large American computers as Univac-II or Univac-Scientific. It is installed in an 8.3 meter long van and features high speed -- 50,000 operations per second with an internal memory bank capacity up to 28,000 words and external up to 1 million. The computer weighs approximately 6 tons and costs between 1.5 and 2.5 million dollars, depending on its makeup. Some of the computers are illustrated in Figures 14-16.

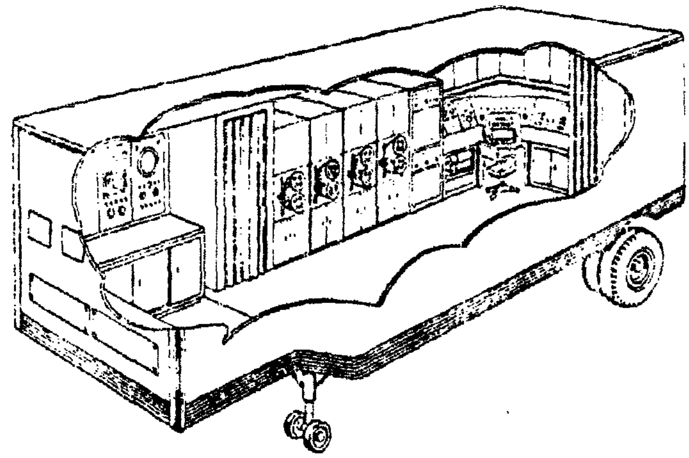

Figure 14. "Moby Dick" -- electronic computer for field army headquarters.

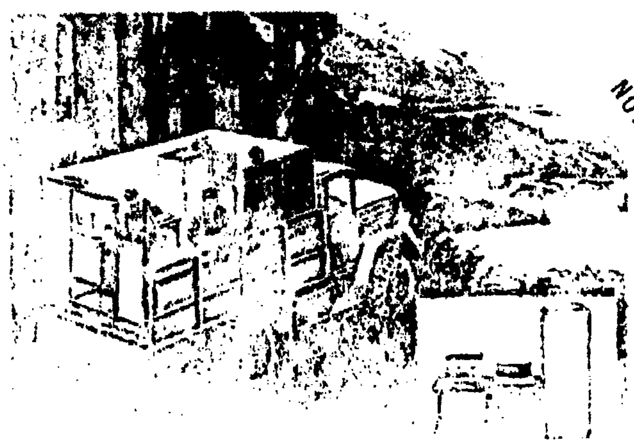

Figure 15. "Basic Pack" -- electronic computer for division headquarters.

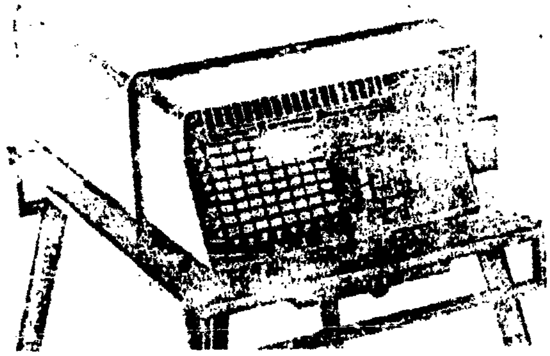

Figure 16. Electronic computer for artillery division.

In the opinion of American specialists field tests of "Moby Dick," conducted in early 1960, produced satisfactory results and verified the viability of the computer after long trips over rough roads. The Sylvania Company has just been awarded the contract to build a series of computers designed for operation in the headquarters of seven U.S. Armies. In the future the existing automated troop supply system will be updated on the basis of these computers and computers will be installed in the personnel department and other offices of the U.S. Department of Defense.

Development of the prototype "Basic Pack," according to the journal *Computers and Automation*, was concluded toward the end of 1960, after which it was sent to Fort Huachuca for testing. This computer is several times smaller than the "Moby Dick." Its weight, including auxiliary equipment, is 2 tons. Other components of the "Fieldata" system, as mentioned in the foreign press, are still in the developmental stage.

Equipping of the army with mobile electronic data computers is big business for the American radio electronics industry. And not only because they have to manufacture large quantities of computers for infantry headquarters. Military computers require development of an entire complex of auxiliary equipment including, in particular, apparatus for hooking up with communications lines, systems for printing the situation on cards, input and printout systems, various control systems. Therefore the development of the "Fieldata" system prototype has recently attracted many new companies. Stelin, Collins and Bendix-Pacific, for instance, are developing automatic data input systems designed to operate at speeds of 30 to 500 words per second. Smith-Corona, Ampex and other firms are manufacturing data input and printout systems -- electric typewriters, reading devices, perforators, printing devices, tape transports, etc. It stands to reason that all this work is being done by military contracts.

The proprietors of the American radio electronic companies are wringing their hands with joy. As reported in the foreign press the U.S. Army has a special plan for acquiring mobile computers for data processing under field conditions all the way up to 1970. The period 1965-1970 will have a completely operational and improved military data processing system, called the "Armydata."

As seen, automation is encompassing to an ever greater extent the American Army. Generally speaking this process is objectively natural, as is natural in any army the development on a modern technological level, of troop control systems that have undergone no real improvement for many decades.

Considering the possibilities of modern computers: their capacity to "memorize" up to 5-10,000 letters or numbers per second and to perform with great speed up to 20-30,000 arithmetic operations, foreign specialists positively evaluate the need to introduce computers along with other means of modern computer technology to improve labor productivity of the commanders and headquarters in the solution of military problems of the first two types -- computational and informational. It has been stated in many foreign sources that headquarters work can be made approximately five times more efficient by this method. Meanwhile military specialists are turning their attention to the capability of computers to solve logic problems -- to compare several numbers, determine the largest among them, list numbers in any required order, find even and negative numbers. It is considered that if also the laws and rules by which a commander solves certain logic problems related to decision making can be found and mathematically expressed, the solution of these problems may also be turned over to the computer, thereby improving the commander's labor productivity.

It is considered here, of course, that each commander solves tactical problems differently, according to his individual "mannerism." Under identical combat conditions, therefore, various commanders will make different decisions. Nevertheless, the objective laws of carrying on combat actions, which can be discovered and formulated on the basis of analysis of a large number of actions, carried out under comparable conditions and on comparable scales, should be manifested in these decisions with some degree of completeness. These laws include, for instance, the laws of movement of military supplies and military units on the battlefield, the laws of search and detection of targets, laws of firing and certain others.

The ways proposed in the foreign press for solving military logic problems with electronic computers are based on consideration of quantitative and qualitative indices, such as troop training, quality of training, condition of the terrain, weather, and many other factors. But before input into the computer, all considered qualitative factors should be transformed into quantitative factors expressed through certain numbers, because the computer understands only numbers. Can this be done? It is pointed out in many sources that it can be done for certain quantitative factors.

Thus, rainy weather -- a qualitative factor -- affects the viscosity of the soil, i.e., the condition of the terrain and its passability. This, in turn, affects the average rate of movement of the troops, which is determined by the number of kilometers traveled by a given form of vehicle per unit of time, and is in fact a quantitative factor, expressing in this case a qualitative factor -- the effect of weather. Rainy weather, on the other hand, hampers observation of the field of battle and thereby impedes target search, which can be expressed quantitatively -- as the number of targets spotted in a given section of the front or by a given unit in a certain interval of time. A qualitative factor -- troop training -- can also be expressed quantitatively with the aid of such numerical indices as firing speed, firing accuracy, time of completing certain operations, etc.

Quantitative consideration of the elements of terrain is of special importance in the solution of military logic problems. Let us examine, for example, one of the methods printed in the press for feeding linear terrain elements -- highways -- into a computer. We will assume that the machine works with a digital code with the following conditional symbols: 100 -- first class road; 200 -- second class road; 300 -- third class road. The digits in the zero positions will denote the length of a section of a first class road. Then the road between two points, the locations of which are denoted by digital coordinates (see Figure 17), can be fed into the computer in the following form: 714, 445, 125, 733, 458, 220, 747, 448. This combination of numbers is read as follows: between points with conditional coordinates 71.4, 44.5 and 73.3, 45.8 there is a segment of first class road 2.5 km long, and between points 73.3, 45.8 and 74.7, 44.8 there is a segment of second class road 2 km long. In this way the characteristics of railroads and waterways can also be symbolized and fed into the machine along with their indices, which determine the condition and passability of individual segments.

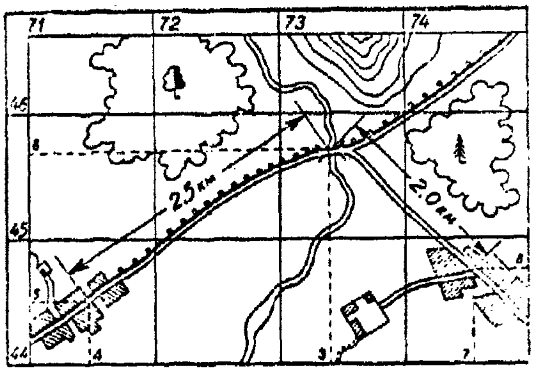

Figure 17. Coding of transport system.

Using the computer, into whose memory bank are thus fed in data concerning the road system in the region of military actions, it is possible almost instantaneously to obtain the answer to such logic problems as the choice of shortest routes between any points in a given region, most suitable distribution of troop columns on the routes, calculations of movement graphs, planning of troop movements from certain points to others in the shortest period of time, etc. But before the computer can solve the required problem, into it must be fed, along with the initial digital data, a program, in accordance with which these data are to be processed and the required answer obtained. Such a program is written on the basis of analysis and repetition of the experience of the solution of such problems by man and is also written in digital form.

It has been reported in the press that headquarters equipped with a special computer scored higher with respect to all indices (time of operation, accuracy and effectiveness of decisions made) in a series of command headquarters exercises than the "enemy" headquarters without an electronic computer. Obviously there are some exaggerations in individual press reports, although there is no doubt that these computers, as the basic means of automation of control processes, deserve serious attention. These computers are just as important in troop control as was, in its day, the invention of communications systems.

Electronic computers make it possible to automate even such a laborious process of headquarters work as plotting situations on a map and writing documents according to preprinted standard forms. This is achieved with the aid of special electron tubes of the television type, which display signals from the computers. Efforts are under way in certain countries to directly plot situations on a map from information obtained by computers. Some of these systems ("Datatron" and "Dataplotter," shown in Figure 18) are also being mass produced as appliques to computers.

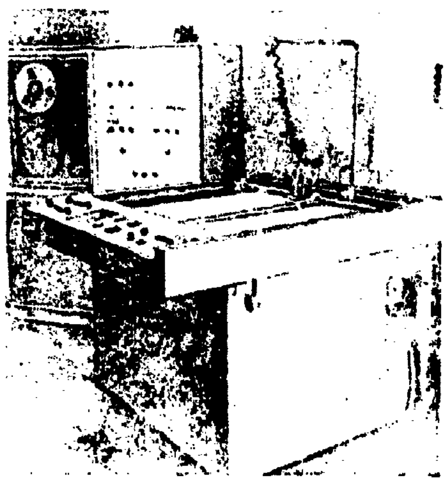

Figure 18. "Dataplotter" -- system for automatic plotting of situations on map in two colors.

Capabilities of means of mechanization and especially automation of headquarters work have not yet been analyzed to a sufficient degree. Undoubtedly the last word has not yet been spoken. In the future, as printed in the press, we may expect the appearance of new technical means of mechanization and automation of troop control.

In this connection certain foreign theoreticians of "pushbutton warfare" are raising from new points of view the problem of designing completely automated (without people) missile, artillery, tank, aviation and other complexes, controlled by an "electronic brain," which performs in the lower echelons the executive functions of the commander. However, the problem of the replacement of man by computer has no practical significance, despite what would appear to be the substantial penetration of modern electronic technology into the sphere of intelligent human activity, and is raised by bourgeoise "theoreticians" for pseudoscientific purposes. Indeed the control of combat is not limited simply to giving orders and commands by the commanders. It is based on a system of voluntary acts and organizational work directed toward the realization of decisions that have been made, i.e., requires actions which the computer cannot consider and perform.

Therefore, as applies to the electronic computer, the name "electronic brain" that has been tacked on the computer abroad is not correct. Man is the creator of the computer and in view of this is much more intelligent than his creation, which does not have and cannot have the capacity to think creatively, and which therefore needs constant human help and supervision. The progressive importance of the introduction of headquarters electronic computers to the military consists not at all in that they will some day completely replace commander and headquarters personnel, but in the fact that they are capable of freeing them from a large volume of monotonous mental work and giving them time to perform direct work related to troop control.

The fact that on the present level of science and technology electronic digital computers can solve not only data and calculation problems, but also logic problems and therefore play not only the role of informer and calculator for the commander, but also the role of his "adviser," should not give rise to false notions. The more factors influencing victory in battle can be fed into ahead of time, the higher will be the quality of such a "adviser." However, by no means all these factors can be written in computer language, and consequently they cannot be considered. In this connection the role of automatic "adviser" cannot be unlimited. As certain of the more controversial foreign specialists point out, at best only a few variants of a battle plan can be worked out ahead of time with the computer and the most probable evaluation of the expected results obtained. However, the choice of final variant and, along with that, all the work and responsibility involved in carrying out this variant will rest upon the commander's shoulders.

CYBERNETICS PREDICTS

Colonel-Engineer P. Tkachenko, Candidate of Technical Sciences

When the Oracle Does Not Err

Throughout history troops sent out on a campaign wanted to know in advance whether they would be victorious or not. They called upon the oracle. The bearded old man watched the flight of birds or explained the position of the planets in relation to Mars. And finally he announced: "You will be victorious." Or conversely: "Mars promises defeat."

There is no need to explain how unsuccessful is such "foresight." In our day, of course, no one would think of trying to find a causal relationship between the motion of the planets and the results of battle. However, the need for predicting the outcome of certain actions in combat has not vanished, but has become even more important. Military specialists, who during peacetime develop new tactics of troop actions, want to know how effective they will be. The designers of new missiles, tanks, aircraft, ships need to determine which of them are best. Of course many answers to such problems are found through military exercises and testing of military equipment. There are numerous cases, however, when these methods do not produce the desired results.

And what about in combat? There are many cases when it is necessary to rapidly predict how events will unfold under the influence of various factors, not to mention weather forecasting, which can have a considerable influence, let us say, on troop movements. What oracle can be called upon for help? In our time the oracle is cybernetics, in particular its new branch -- analysis of operations. True, the word "operation" here is in no way identical to the same military term. This word means, generally speaking, any activity in any field of life, performed under supervision and repeated many times according to a plan.

It is pointed out in the foreign press that a method has been developed in recent years for forecasting individual aspects of the military activities of troops. As a result military specialists can obtain answers to questions as to what forces and weapons can achieve the desired result of individual stages of combat actions, how certain processes will develop under certain conditions. Here, of course, we speak not of replacement, displacement of man by some mathematical "omniscient" computer.

Man has long been interested in the results of his activity, of certain natural and technological processes. In trying to predict them he selected and analyzed a certain quantity of data and, on the basis of calculations, found, to some degree of accuracy, an answer to the question of interest. The progressively increasing significance of cybernetics is that it frees man from laborious calculations and increases his labor productivity on colossal scales. And by invading the realm of prediction of the results of certain actions and processes, cybernetics looks for possibilities of assigning the solutions of such problems to computer technology, leaving man with only the control of this technology and analysis of the results obtained.

From the point of view of cybernetics all problems of forecasting are divided into two groups -- technical and logic. In the technical problems natural phenomena or physical processes not related to human participation are forecast. Included here are weather forecasting, forecasting the motion of artificial earth satellites, etc. Logic problems deal with forecasting individual aspects of human activity. Let us see just how cybernetics solves these problems.

Tool of Forecasting

In order to predict the behavior or development of the phenomenon or process of interest to us with the required accuracy it is necessary, on the one hand, to have a forecasting method and, on the other hand, the means of realization of this method. At the present time such means are electronic computers, and the methods are given to us by mathematics, and in particular such branches of mathematics as probability theory, mass servicing theory, games theory, and modeling theory.

The problems of forecasting are solved on ordinary general-purpose electronic computers. However they should have, in addition to the basic systems common to all general-purpose computers -- control, external and internal memory, arithmetic system and data input and output systems (see Figure 19), random numbers and time pickup units. What are these devices?

The random numbers pickup unit is often figuratively called the electronic ruler. It is used for generating numbers according to a law of equal probability -- numbers whose probabilities are identical and do not depend on their quantities and method of generation. There are many methods of producing random numbers, including sampling from special tables. The tossing of a coin is also one of the methods of obtaining random numbers "0" or "1" if it is agreed upon ahead of time that these numbers are related to certain sides of the coin. In electronic computers it is most convenient to use for the generation of random numbers, and consequently of all numbers formed from them, devices that randomly produce electrical pulses and

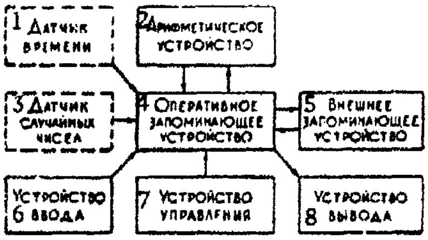

Figure 19. Block diagram of electronic computer. KEY: 1, Time pickup; 2, arithmetic unit; 3, random numbers pickup; 4, operational memory bank; 5, external memory bank; 6, input system; 7, control system; 8, readout system.

transform them into random sets of zeroes and ones corresponding to different numbers.

Electronic "ruler" and the random numbers produced by it are required in order to select one of the possible directions of development of a forecast process. We will assume, for instance, that further development of a process can proceed with equal probability in one of three different possible directions. The electronic ruler helps us to select one of the possible directions in a given situation. If indeed the probabilities of development of the process in the different directions are different, then this too can be considered a random numbers pickup unit. Thus, if the probability that a process will proceed along one of the paths, let us say is twice as great as on the others, then the random numbers corresponding to this path should appear about twice as often as the random numbers corresponding to the other possible directions of development of the forecast process.

The time pickup unit is required in order to generate and produce signals of the real or conditional time, according to which the real time of completion of the process of interest to us could be determined. We will note that it is not altogether necessary to forecast a given process during all the time that it takes this process to proceed. In this case there is no benefit to be gained from forecasting, particularly when forecasting is started together with the beginning of the real process. And there are those processes which last for an extremely long time, but the possible results of them must be predicted long before their conclusion. In this case accelerated forecasting methods are also required. However the time of forecasting and the time of process completion should be known at all times. The time pickup unit is used for this purpose.

The random numbers and time pickup units are illustrated in the diagram of the general-purpose computer (Figure 19) by the broken lines.

Events of which it is known that they must take place yield most readily to forecasting. These events have rigid, completely defined or, as is often said, determined relationship among all values influencing their result. Such events include, for instance, lunar and solar eclipses, tides, motions of various bodies in water and air. The objective physical laws that these events obey are well known and enable us to determine with a certain degree of accuracy the time and duration and only possible result of each event.

There is also a set of events whose appearance cannot be predicted with total definition. These include earthquakes, atmospheric precipitation, the results of military actions and firings, etc. On the other hand there are events of which it is known that they must take place, but the results of these events can be uncertain. Thus, after launching a missile must fall to the earth, but its effect on the target can be predicted with only a certain degree of probability.

It is not hard to see that most of the above examples pertain to problems of technical (or physical) forecasting. Only one of the problems (determination of the results of combat actions) is a problem of logic forecasting of events involving human participation, which has a real and uncertain effect on the results of these events. Examples of such events, however, can be cited *ad infinitum*, recalling various events or processes from the realm of military activity, industry or agriculture, which proceed with the participation of individual people or groups of executives. The forecasting of such events is done with the aid of the theory of mass servicing, games theory and modeling theory, which belong to branches of mathematics which have undergone the most intensive development in recent years. Such classical branches of mathematics as differential calculus and probability theory are quite sufficient for forecasting the results of most technical problems.

Let us consider specific examples of how certain problems of importance in the military are forecast.

After an Atomic Explosion

A typical example of a technical problem of forecasting is the prediction of the radiation situation in the region of combat actions where atomic weapons are used. The commander would like to know ahead of time the levels of radiation after a possible nuclear detonation. Such a forecast would enable him to select the routes of travel on the battlefield and to determine contaminated areas.

The essence of forecasting the radiation situation consists in scientific prediction of the direction in which the radioactive cloud of an atomic explosion travels and the degree of contamination of the land along the cloud's path. In foreign literature several methods are given for the solution of such a problem. The simplest one is to use templates made up ahead of time for nuclear weapons with several different TNT equivalents and for the prevalent wind velocity. If the actual conditions correspond to those for which the template is constructed, it is possible by superimposing the template on a map and tracing it with a pencil, to quite easily forecast the possible contamination boundaries (see Figure 20). Thus the answer is found rather easily and quickly but is extremely inaccurate.

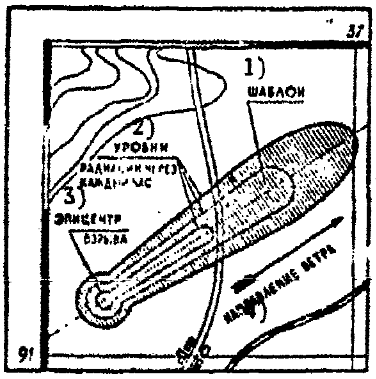

Figure 20. Forecasting boundaries of radioactive fallout zone. KEY: 1, Template; 2, Levels of radiation after each hour; 3, Explosion epicenter; 4, Wind direction.

The greatest errors are obtained here due to possible changes in wind direction and also because the height of detonation of the atomic bomb, character of the terrain and soil, mutual influence of near-by explosions are not taken into account. These deficiencies can be avoided to some degree by using another method -- calculation of the levels of radiation using equations that take into account the power of the explosion, direction and velocity of the wind. Here, however, a large volume of calculation is required and it may turn out that being already performed they are simply obsolete. In the opinion of foreign specialists it is not advisable to adapt the electronic computer for this purpose -- the forecasting method itself is not accurate enough. Most suitable, as stated in the press, is another -- so-called analytical method. It, in particular, is based on solutions of the problem of forecasting the radiation situation in the U.S. Army. What is the essence of this method?

The mushroom cloud that forms after an atomic explosion is saturated with the fission products of the bomb and soil particles lifted up by the explosion, which have become radioactive. When they settle back to earth they will cause radioactive contamination. In order to predict its level the cloud is sectioned into several layers, as shown in Figure 21. The height of the layers is set so that the time of free fall of the particles from a given layer to the earth's surface will be proportional to the altitude of the given layer. Then the areas of the terrain onto which particles traveling under the influence of the wind and gravity will fall from each layer are determined.

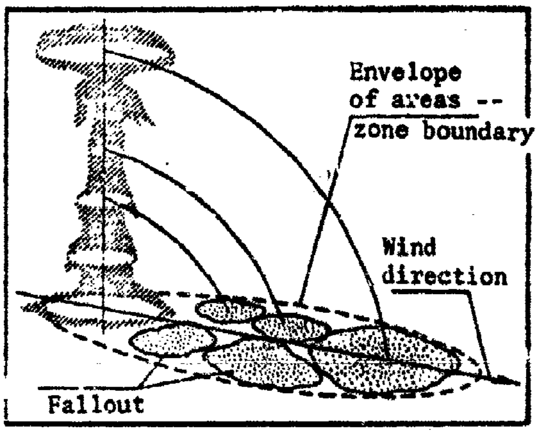

Figure 21. Forecasting levels of contamination.

After this the traced outer contour of the areas of fallout from the cloud will become the boundary of the radioactive fallout region. The sum of radioactivities of the individual fallout areas, in fact, determines the level of contamination of the terrain. And since the particles do not fall from the cloud simultaneously it is possible, by determining the boundaries of the regions of contamination and the levels of radiation through certain intervals of time, to obtain a complete forecast of the radiation situation for several hours in the near future.

It should be pointed out, however, that it is not possible to do all the calculations required for such a forecast with the aid of the ordinary calculation equipment -- slide rules, arithmometers, etc. The volume of calculations is too overwhelming. To perform such a large volume of calculations with great accuracy, a man using an arithmometer would have to work for more than a month without stopping. Obviously such a forecast would be of no practical worth. And here we have a contradiction: approximate, rough methods require less time but yield inaccurate results; precise methods, on the other hand, are very complex and are unsuitable under field conditions due to enormous time expenditures.

What is the alternative? The use of electronic computers. Only they, as is stated in the press, can put the solution of many forecasting problems, including the problem of forecasting radiation situations, on a practical footing.

It is stated in the foreign press that the small-scale portable electronic computers that have been developed in recent years can rapidly solve under field conditions extremely complex forecasting problems in short time, a thousand times less than with the aid of other computational equipment. Even on an electronic computer, which automatically performs 5,000 arithmetic operations of the addition and subtraction type in one second (and under modern conditions this is considered slow), the radiation situation can be forecast analytically in only one minute.

Predicting Victory

Along with technical problems, in which it is required to predict the outcome of physical processes not involving human participation, cybernetics deals with those in which it is also necessary to forecast human activity. Such problems (they are called logic) include, for instance, forecasting the results of individual stages of military actions.

The statement of such a problem in itself is nothing new. Throughout history military commanders, in selecting the best course of actions, have asked themselves: "And what will be the ultimate result?" Considering mentally the effects of various factors, they try to foresee the result of each variant of the solution. The best course of action was selected on the basis of comparing the conclusions obtained.

This is the same line of reasoning that military cyberneticians employ. Their aim, however, is broader: find the laws of action of various factors at certain stages of military actions and give the commanders the most rational methods and weapons, with which they will be able in shortest time and with greatest accuracy to evaluate their decisions. The possibilities that exist here can be judged on the basis of examples printed in the foreign press of forecasting certain actions of a tank company in combat.

The first step in the solution of logic problems of forecasting is to select the criteria or, in other words, indices by which the results of the investigated actions can be evaluated. As regards the actions of a tank company, they can be judged either by the losses inflicted upon the enemy by the tank company during a certain period of time, or by the number of kilometers by which the tanks advance into enemy territory in the same time or, finally, by the number of tanks lost by the company. But as seen, each of these criteria reflects only one aspect of the company's activity. Obviously, the best generalized criterion is that which takes into account the greatest number of its action characteristics.

In order that the generalized criterion characterize as completely as possible the result of actions of the tank company, it must include the losses inflicted on the company by the enemy. This is easily done, however, only in the case of tank to tank combat, when the losses are expressed through like values. In fact, all enemy losses, which may consist not only of tanks, but also other forms of military equipment and manpower, can be considered as a whole only when the losses of a different category are expressed in commensurate units.

Thus, if it were possible, for instance, to establish that a medium tank corresponds to 1.25 of some conditional units and a 75-mm field gun has only 0.5 such units, then it could be assumed that one enemy tank knocked out is equal to 2.5 of the guns that destroyed it. Thus it would be easy to reduce all losses to losses of "conditional tanks," which can also be considered in the forecasting problem. However the development of single conditional units of measurement of losses for all forms of weapons is, according to statements of the journal of the American society of operations analysis, a very complex problem. In this connection the generalized criterion used in the problems of forecasting military actions solved abroad, cannot yet take into account the losses suffered by the enemy during the course of combat, which influences to some extent the quality of the forecast.

And generally speaking, the accuracy of the forecasting of logic problems is lower than that of technical problems. This is because the processes being forecast in technical problems obey well-defined objective natural laws, described by systems of mathematical equations. In logic problems it is necessary to consider subjective factors, which characterize the behavior of people and their decisions in various conditions. And since different people make different decisions, even under identical conditions, the solution of logic problems cannot, in principle, be completely accurate and reliable.

The result of such forecasting should be regarded as reliable on the average for a large number of cases. Here, however, it can be said beforehand, for instance, that the forecast is valid in 85 cases out of 100. Logic forecasting is also characterized by results that are valid only when one or several conditions are satisfied. Suppose the solution of a problem can be given only in the following form: "If a company advances with a left echelon military formation and if the enemy does not call the reserves into the conflict, then we can expect losses in this battle not exceeding 0.12 tank per one kilometer of advance of the company."

Thus we will assume that we have a more or less satisfied criterion of certain company actions. In making their forecast it is necessary to determine the magnitude of this criterion on the basis of the initial deployment of our forces and enemy forces, character of the terrain, creative decision made concerning actions of our troops and certain assumptions concerning enemy actions. In other words, if on known terrain the deployment of the fighting sides is given and their methods of actions is known it is necessary to predict the position of the sides and to evaluate quantitatively their losses for some period of time after the beginning of the fight.

The mathematical tool used for finding the answer to this question is the so-called model of combat. It can be developed on a computer. The model of combat is the same thing as writing a special program for the computer. Using this program the computer scans in some order the information stored in its memory, processing this information and updating it.

As it applies to our tank company, the memory of the computer should store in the form of conditional combinations of numbers information concerning the terrain, our tanks and enemy tanks. For this purpose the map of the terrain in the battle area is divided into quadrants. Each quadrant is characterized by the mean elevation of the terrain in it, height of vegetation, the presence of natural or man-made obstacles, character of the soil and passability. All these data are prepared beforehand, coded and fed into the computer's memory.

Random deviations in the actions of combatant sides deserve special attention. They occur any time that it is necessary to make one of several possible decisions. This happens, for instance, when dealing with the problem of surmounting an obstacle on the right or left if the conditions of bypassing the obstacle are absolutely identical on both sides. Or two identical targets appear, located at short distances from each other under identical conditions. The decision as to what target to hit first under these conditions may also be of random character.

In computers designed for modeling combat actions there is, as already mentioned, the so-called electronic ruler. It generates randomly, that is to say that it cannot be predicted beforehand, zero or one. The appearance of zero or one is related to the choice of one or another variant of the solution in actual combat, the outcome of which is predicted.

There may in practice also be cases with three or more equivalent variants of the solution. This, naturally, hampers the choice of specific variant. For these cases too, however, as stated in the press, mathematical methods have been developed for modeling on electronic computers. Thus, the "electronic ruler" as a whole makes it possible to consider random deviations in human actions, which lead to a situation that even under identical conditions different people will make different decisions.

Let us return to our example. Before we can predict the most probable character of actions of a given type of crew in the near future in consideration of random deviations, we must bear in mind the location of this tank in relation to its neighbors and the enemy. Moreover we must determine the field of visibility for this tank on the terrain, evaluate the possibilities of detection of targets and of firing at them and also bear in mind many other factors. The solution of such partial problems requires an enormous volume of calculations. They too can be carried out only with the aid of the electronic computer.

Consideration of current time poses certain difficulties. It is not possible to instantly forecast the military actions of an individual tank over a long period of time. The combat situation may change abruptly and the forecast becomes worthless. Therefore the need arises to forecast simultaneously the actions of all tanks -- friendly and enemy, but for short periods of time. During this time the mutual distribution and, consequently, the mutual effect of the weapons on the battlefield cannot change substantially. The results obtained from the forecasting of military actions for a short time interval will be the initial data for forecasting the subsequent short time segment, etc. As a result the most probable outcome of actions of sides in combat can be predicted for a considerable period of time. But in order to obtain stable forecasting results each battle should be "fought" many times on the computer under identical conditions and with identical initial data. Indeed the result of predicting an individual battle is, to some degree, a random event. However, the average result of a large number of identical battles will be valid.

What is the practical worth of such methods of solving military logic problems of forecasting? Many foreign specialists agree that their further development may give the commanders a potent means of rapid preliminary evaluation of planned actions. Under contemporary conditions the commander, before making the decision, evaluates several possible results of steps taken. The use of computerized logic forecasting increases their number manyfold and thereby permits the commander to act with the greatest probability of positive outcome of planned actions. However, as mentioned in the foreign press, the specialists have a lot of work to do before the armed forces will have such a capability.

The press also mentions the positive effect that can be obtained by using computerized forecasting methods and by training command personnel. In this case it is possible without involving troops to evaluate rapidly the results of the commanders' solutions of individual training problems on conducting military actions.

THE COMPUTER AND WEAPONS SYSTEMS

Lieutenant Colonel-Engineer A. Prokhorov

Among all the machinery and mechanism which man has created, some are general-purpose computers, capable of performing many different functions. However it is hard to find another such "master of all trades" as the electronic digital computer. It is found in the scientific laboratory, in the factory and in the clinic. Electronic computers also perform various functions in the military. Very important among them is control of individual forms and entire complexes of weapons systems on land, on the sea, in air and space. Indeed, here too many calculations must be performed, and when it comes to the electronic mathematicians it is difficult for even their creator -- man -- to compete with them.

For Air Defense Systems

Under contemporary conditions protection against high-speed, high-altitude and low-flying aircraft is very difficult. This is because the time of action of active air defense weapons -- antiaircraft guns, fighter-interceptors and guided missiles -- is limited to a minimum. There is a critical need for weapons systems whereby commanders can concentrate in a short period all the data they need concerning the air situation and be able to choose rapidly and correctly the most effective weapons and military equipment. As shown by the investigations of foreign military specialists, these requirements are satisfied by air defense systems based on high-speed electronic computers. Of what do these systems consist?

The heart of the system is a rather large and potent electronic computer (see Figure 22). In its memory bank are entered ahead of time the "addresses" and military characteristics of guided antiaircraft missile batteries, fighter-interceptor airfields and antiaircraft artillery batteries. The command posts of the units of these weapons systems are hooked in with the computer by communication lines, over which control commands are transmitted.

When enemy aircraft appear, long-range radar stations begin to determine their precise coordinates: azimuth, range and altitude, which are continuously transmitted to the computer. The computer's program is written in such a way that when the coordinates of a target change it automatically calculates its speed, course and automatically begins to solve the problem of interception, simultaneously selecting the air defense systems best suited under the developing conditions for destruction of the target, based, for example, on their location and range capabilities. As soon as the weapons systems are chosen, the computer sends a signal to the command post, to the fighter-interceptor unit headquarters or to the ground-to-air guided missile fire control center. Here a definite decision has already been made concerning interception of the airborne target.

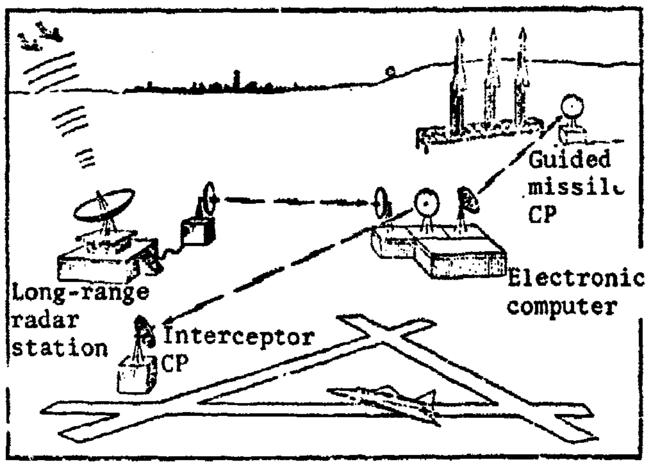

Figure 22. Electronic computer in air defense system.

In cases when fighter aircraft are used for interception, guidance commands can be transmitted from the computer, being the command post, directly to the aircraft until it enters the target intercept zone calculated by the computer. The pilot guides the aircraft independently to the point of firing. For this purpose he uses the on-board computer, which automatically determines the trajectory of attack required for target destruction and the time of opening fire on the target.

But if the electronic computer at the control center selects for target destruction guided antiaircraft missiles as the best in the given situation, then the corresponding commands are transmitted to another computer, located at the fire control center of the missile complex. It, in turn, solves the problem of which battery or groups of batteries to use for destroying a given target and transmits the required coordinates to the ground guidance systems, which guide the missiles to their targets.

Computers of a type different from electronic computers can also be used for controlling ground air defense systems. Among them are, for instance, computers with continuous solution of the problem of striking a target with a missile, used in many countries for fire control of automatic antiaircraft guns that are effective against low-flying aircraft. Here the computer automatically performs a number of mathematical operations -- differentiation, multiplication, algebraic and geometric summation, functional transformation and integration. As a result an anticipated target can be fired upon with an accuracy of 0.1% of the sloping range. As stated in the press, certain target destruction is guaranteed when several automatic antiaircraft guns are used to repulse an attack.

For Air Command

Military air command in modern armies consists of a large number of units and elements. They are equipped with a tremendous quantity of aviation, missile and auxiliary equipment. Many people of different levels of professional preparation, working on various military problems, service and operate it. How can this arsenal and personnel be controlled? The electronic computer, groups of computers, or even the entire military operations control system can be useful here. An article concerning one of such systems, for the U.S. Strategic Air Command, was recently published in the journal *Interavia.*

This system is designed to provide air force headquarters with information concerning the condition and combat readiness of bomber and missile units, and also for rapid transmission of military commands. It calculates and produces information concerning the number of combat-ready strategic bombers on the ground and in the air and also concerning their fuel supplies; concerning the number of combat-ready ballistic missiles; number of aircraft and missiles being checked and repaired, and also concerning the availability of combat crews. In addition, this system provides rapid -- in a few minutes, performance of exceedingly complex calculations related to various operations.

The military operations control system of the Strategic Air Command consists of four basic subsystems. The first is the subsystem of automatic terminal stations, located at bomber and missile bases. Information concerning the technical condition, location and preparedness of subordinate units, fuel supply and spare parts, availability and preparation of aviation and technical personnel, weather conditions, activities and intentions of the enemy can be fed in manually to a terminal station from the command center of an individual base by means of teletype or automatic report composer. Special systems code these data and transmit them via communication lines to a second subsystem.

The second subsystem controls the transmission of reports from terminal stations and consists of a series of communications control centers. Each such center, connecting some group of terminal stations, controls the reception and transmission of reports and instructions. Here the computers automatically check the validity of incoming reports and record them on tape. Then the reports are transmitted to the consumers over strictly controlled communication lines. The program-memory computer is the foundation of each center of the second subsystem.

The third is the data processing subsystem. The heart of this subsystem is a large electronic computer with an enormous memory volume. It processes information received via communication lines, checks it and, using a specific program, performs calculations required for carrying out certain operations and prints them out in tabular or graphic form.

Fourth is the indicator subsystem. It consists of visual screens and automatic projectors, by means of which information arriving from the computer is projected on screens. It is used by command center officers of the Strategic Air Command for controlling subordinate headquarters and units.

The battle plans during an alert are continuously changed, depending on intelligence received concerning the enemy. These changes are reflected on a special screen at the command center. This screen is 30 meters wide and 5 meters high. It is located on one of the walls of the underground facilities of the CP. The entire opposite wall is occupied by the "command balcony," where the staff officers are stationed opposite the screen. Below the balcony are numerous projectors. These projectors display on a screen the information required for controlling military actions -- maps, diagrams, tables. Information is rapidly processed by a computer located in the adjacent room and some of it is printed out in the form of printed text.

On Strategic Bombers

At the present time, as we know, air navigation is unthinkable without the aid of special systems by which it is possible to determine at all times the course and speed of an aircraft in relation to the earth, drift angle caused by the wind, geographic location of the aircraft, and target range. No matter what method is used to determine these values, the navigation system (as the basic unit) must include a device that performs navigational calculation using these initial data. A computer can be used as this system with great success.

One of the foreign-designed on-board navigational computers weighs only 52 kg. It continuously determines according to a given program the position of the aircraft and, considering the coordinates of the point at which the bombs must be dropped, determines the required course and transmits "commands" to the controls through the autopilot. The program of this computer can be written so as to guide the bomber to several successive targets.

The bomber navigational system also must include an on-board computer. It uses navigational data and target coordinates, determined by the on-board radar, to solve the problem of precise target bombing. And if the bomber launches a guided missile of the "air-to-ground" type the on-board computer and the requirements on it are expanded even more. To the determination of the moment of missile launch in this case is added the problem of accurate guidance of the missile to the target.

The solution of the problem of missile guidance to the target is divided into two stages. First, using the ground electronic computer, the trajectory from the point of launch to the target is calculated and the program of operation of the on-board computer is written. In flight this computer automatically performs calculation of the actual flight trajectory and compares it with the prescribed trajectory. Considering their difference, the computer deflects the control surfaces of the missile so that the true and calculated trajectories coincide.

Ship Computers

As in the organization of ground air defense, the air defense system of fleet ships is also based on electronic computers. Here individual firing complexes of active air defense systems of ships, for instance guided anti-aircraft missile carriers, are equipped with on-board computers which calculate the data required for firing upon enemy aircraft. The electronic computers of the navigation system of patrol planes based on aircraft carriers and shore airfields also play an important part.

Much attention is being devoted at the present time in foreign navies to ships and missile submarines. In order to combat sea-going and land targets successfully with missiles it is essential to know the geographic location of the ship from which the missile is launched and target location. Here too the electronic computer is useful. The computer of the ship navigation systems determines continuously and with great accuracy the point of launch of a missile against a target with given geographic coordinates. During the process of flight the on-board computer of the missile continuously compares the required trajectory with the actual trajectory and, when they do not coincide, generates the required commands, ensuring guidance of the missile to the target.

The development of entire systems for controlling the actions of ships, also based on computers, has also been reported in the foreign press. One of such systems is the U.S. NDTS system, designed to ensure combat viability of different types and classes of ships under all possible conditions. The equipment of which the system consists produces various information and prepares data for decision making in a combat situation. Among the important advantages of the system are that it frees personnel, especially operators (to the maximum possible and practical extent) from laborious and often repetitive operations, which enables them to concentrate most of their efforts on decision making.

The automated NDTS system performs the following basic functions: coordinates the collection of data from sources located aboard the vessel (radar and sonar stations, navigational and other systems) and from external sources; compares these data in order to produce a reliable and clear picture of the tactical situation; prepares data required for decision making; transmits decisions made to selected weapons systems. The system consists of various electronic equipment: high-speed general-purpose digital computers, devices for automatic transmission of data in digital form, digital analog indicators and apparatus for processing videosignals of radar stations, memory banks based on magnetic drums and other equipment.

It was stated in the press that the NDTS system very effectively uses data concerning the tactical situation, received on each ship by independent methods, and makes it possible to use the information processed on other ships of a force, thereby permitting more effective evaluation of the entire tactical situation. Moreover, the system improves the reliability of execution of commands of higher command and especially commands related to the guidance of fighter-interceptors or missiles to airborne targets.

It is worthwhile to discuss briefly digital computers of a system as its fundamental components. Each computer occupies a volume of about 1.4 m^3 and requires about 2 kW of power. Its memory capacity is 1 million 30-bit symbols with an access time of 8 microseconds. Data can be sampled arbitrarily from the memory bank without disrupting information. One word can be taken out in 2.5 microseconds. Fourteen different channels are used both for input and printout of data. The system consists of a large number of individual modules, which permits easy installation of units with different characteristics, depending on the type of ship and the problems to be solved by the system.

When ships equipped with the NDTS system, or other naval, surface and aerospace vehicles equipped with systems for data transmission and computers, are located near each other within the range of visibility an automatic short-wave communication line is used as the means of exchange of military information between them. The exchange of information is automatic and continuous between the computer of the transmitting station and the computers of the receiving stations. The methods of controlling the system of data transmission lines provide the required transitions from the reception modes to the transmission modes.

In Space

The expanses of space are infinite and for researchers who desire to enlist it into the service of humanity it opens up unusual horizons. The aggressive circles of the U.S. look upon space in a different light. As soon as the first steps had been taken into the universe they began to formulate a space strategy in the hope of involving space in the arena of war. Now there are several U.S. satellites in orbit around the earth for military purposes. These are spy satellites for photographing strategic ground targets and radio electronic surveillance of air defense complexes, satellites for navigation of missile submarines, satellites for the exact relation between geodesic systems of various continents, which is essential for the aiming of intercontinental missiles, weather satellites and military communications satellites.

In order to ensure operation of the equipment of military satellites it is necessary to monitor their orbital parameters and simultaneously send commands to the satellites. In short it is essential to know the exact situation in space. For this purpose the U.S. has developed a space control system, called "SPADATS."

Information concerning artificial earth satellites and space vehicles arrives at the center of the system from several military and civilian ground control and tracking systems and individual tracking stations. The computer center of the "SPADATS" system is equipped with a computer complex that includes the "Philco 2000" electronic computer, data processing and analysis systems, equipment for receiving and transmitting this information and also various types of indicators. The center controls and tracks all orbiting satellites. As soon as some object in space enters the zone of operation of ground radio electronic or optical tracking systems its velocity, approximate dimensions, orbital parameters and, if possible, purpose are determined and fed into the memory of the electronic computer, which prints out data concerning whether or not the observed object is a known or unknown space vehicle.

The principal purpose of the computer center is to calculate the flight time of each satellite within the zone of operations of the tracking and control stations of the system and to determine data required for rapid and timely detection and tracking of these satellites. The center forecasts the motion of satellites for a two week period. The information from most of the stations is received in open text via teleprinter communication lines, and sometimes in coded form. Most of the information arrives in a form readily transferred to punch cards and then to magnetic tape for input into the computer, which stores the data of up to 500 observations for each satellite.

According to press reports the American specialists are also trying to use computers directly in space, aboard piloted aerospace vehicles.

These are some of the examples of the practical application of computers in various branches of the military. It should be borne in mind that the technology of such computers is rapidly being improved, their weight is being reduced, as are their dimensions and power requirements. As stated in the press, they are being designed more and more to use microminiature units, solid circuitry, micromodules and microcircuitry. The best foreign computers already perform up to 1 million additions per second, can solve rather complex problems in a few seconds. It would not be surprising if in the near future, as a result of scientific and technological progress, the performance characteristics of electronic computers will be even further improved and their ranges of application, which are even now fantastic, ever further expanded. This, of course, will expand the capabilities of the computers in terms of the solution of a wide variety of military problems.

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