Computer simulation as an effective tool supporting decision-making processes in air defense

Adam RADOMYSKI*

Polish Air Force University, Dęblin, Poland; a.radomyski@law.mil.pl, ORCID: 0000-0001-7522-308X

Krzysztof CUR

3rd Air Transport Wing, Powidz, Poland; k.cur@law.mil.pl, ORCID: 0000-0003-4552-445X

Abstract

This article outlines the results of studies concerning supporting the decision-making process in air defense with the use of state-of-the art computer simulator. The simulator is intended to simulate air force operations and air defense in the air, and the simulated facilities are supposed to reflect real and hypothetical facilities. It allows us to conduct experiments with the use of models showing particular fragments of reality, which reduce information entropy characteristic of contemporary decision-making situations in air defense.

Keyword: computer simulation, air defense, command, decision process, simulator.

1. Introduction

The universality of simulation methods has been the main reason for their use in solving problems in air force command. Yet, in the '80s and the '70s, the development of information technology inspired the authors of many theoretical research papers devoted to their use in command. The contents of the research papers preceded real possibilities of the then laboratory simulation models, which were characterized by significant slowness of operation and arduousness in their operation: first af all, the users found it difficult to accept a high number of assumptions simplifying the then mathematic models used to reflect the phenomenon of the battlefield. These disadvantages did not derive from the state of the theory of modelling problems of the battlefield, but from the possibilities of cyber technology at the time. Taking into account all the contemporary conditions of air battlefield in times of crisis as well as in times of war, the air force accomplishes standard tasks, usually in difficult circumstances resulting among others from dynamic changes of operational and tactical situations and the random character of the phenomenon shaping the changes. For commanders responsible for using ground and air elements of air defense, such circumstances cause major difficulties in command, which concern the need to take decisions with hesitation and risk under the pressure of a permanent lack of time [1]. The subjects of decision-making are usually variants of solving decision-making problems, included in the area of responsibility of a particular commander – decision maker. Nevertheless, the random character of conditions causes the uniqueness of decision-making situations. An undoubted advantage of experiments on models of reality without the necessity to bear the real risk of defeat and the costs resulting from bearing losses in real fighting becomes really attractive in the simulation support of air force command. At the Polish Air Force University in Dęblin, the operational-tactical simulator of Air Force ''GAMBLER'' is

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* Corresponding author

used as a tool to support the decision-making processes. Its use during numerous command-headquarters exercises in air defense units proved its applicability. With reference to the subject of studies, it has been acknowledged that the aim of the article will be to confirm the legitimacy of supporting air force commanders in the decision-making processes with the use of modern computer simulators. Besides, it has been acknowledged that achieving this aim will be plausible after solving the main concern of studies which is the question: to what extent will the use of the modern computer simulation in the process of commanding air force influence the quality of decisions taken by commanders?

2. Methodological conditions of simulator in the decision-making process in air defense

The use of the simulator to solve problems of air force command belongs to the group of simulation methods assigned to assess the results of combat operations and war games [2]. In these methods, the main principle is stochastic character of determining partial results and taking them into account during experiments. Problems with identifying the simulation methods, reflecting combat actions are almost identical as in the case of assessing reliability of calculation methods used in calculating phenomenon with appropriate mathematical models [3]. They result from the practical inaccessibility of simulated reality as a model. It is necessary to complete the supporting tools which are being discussed in this article with expert methods. Despite this methodological difficulty, enumerated kinds of simulators and calculation methods are being developed and successfully used in command. The acceptance of these simulators by users results from appreciating the practical advantages of using tools to solve many problems, whose solution, by means of intuitive methods, often prove unreliable, and consequently, worse than one derived from using simulating methods. From the support of command's perspective, the main advantage of simulation combat operations in a simulator is taking into account time and the possibility of studying facilities at any time throughout operations. The possible interactions of both sides are identified in time and space by checking a number of conditions, which are dependent of decisions taken by experiment users performing as decision-makers, in accordance with their qualifications which they have in command systems. The commander has an opportunity to familiarize himself with thepossible development of an air an operational-tactical situation, which results from his decision before it is implemented in real life.

With reference to the simulator structure, the following modules can be distinguished:
- scenario;
- simulation;
- user.

The scenario module, among others, enables one to edit and copy facilities comprising operational-tactical situations in the air (to some extent on the ground as well) and to compile a database of these facilities.

The simulation module enables the following:
- observing a simulation in real time with the possibility of stopping and accelerating;
- viewing selected parameters participating in a particular scenario;
- viewing users of a particular scenario;
- saving a file with a record of the episode;
- downloading a file with a record of the episode;
- having an overview of operational time
- having the possibility of rewinding simulation to any specific time;
- sending messages to both sides playing and receiving messages to all logged in users;
- specifying METEO conditions for every user.

The user's module is an interface for each side (each user), who can make a decision to use its combat capabilities. This module is supposed to be connected with the simulation module processing fast-changing data and to share it with the target user.

This module allows:
- administering all basic facilities available to a side;
- communicating with available basic facilities;
- obtaining information about the state and tasks being accomplished by basic facilities available;
- obtaining information about facilities of the opposite side (in a limited range);
- obtaining information about conditions and terrain of conducted operations;
- scaling the situation (scale change);
- marking and reflecting all zones, areas, corridors necessary to user;
- text communication with a coordinator (simulation module);
- moreover, a coordinator also has an opportunity to manage all capabilities of playing sides, including their state, location, accomplished tasks, as well as changing their states.

The simulation allows us to map decisions taken by both sides, states and events in aspects of time and space, physical results of fight between facilities defined in the scenario, which might be conventionally divided into offensive and defensive potential and potential of defense facilities.

It is also possible to introduce a third user (side of the conflict). The aspect of results of fighting is of accidental character with a schedule determined by efficiency parameters of combat capabilities [3]. Possible relations of fighting, which can take place during simulations are illustrated in picture 1 below.
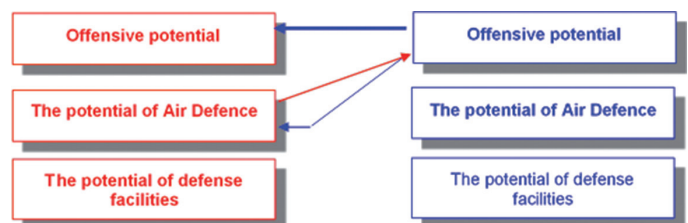
Picture 1. The relation of interactions between combat capabilities in the air.

During simulation experiments, the GAMBLER stimulator, presents the results of decisions concerning using the air force and not only in terms of time and space, but also in efficiency in accomplishing assigned tasks. An account of this efficiency consists in declaring the possibility of task accomplishment with the use of combat assets in particular conditions. After decoding an occurrence of these conditions during simulation, drawing the result of task accomplishment with the possibility and taking into account these results in further simulation then follows. As a consequence of the accidental character of results of identified fights (ground to air, air to air, air to ground or interaction) each result of simulation might vary. Furthermore, in the case of a high number of such drawings simultaneously illustrating the interaction of a high number of homogeneous combat assets, the results of simulation should not significantly vary.
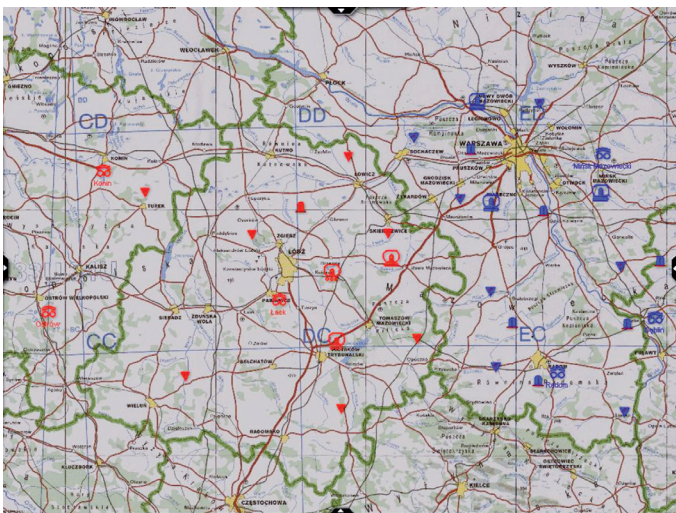
Picture 2. An example of the content of GAMBLER simulator stations shown on the computer monitor when using the tactical situation editor.

In turn, it is hardly possible to achieve the most probable simulation operation (the only one we are interested in during the decision-making process) with the application of a small number of interactions and fights [4]. The measure of difference might be a standard deviation, which in the case of a normal distribution is proportional to the root of the number of simulation experiments. Hence, to increase accuracy of simulation twice, it is necessary to increase their number four times. This can be confirmed by Bernoulli's law *of large numbers or* Chebyshev's principle [5]. In this situation, it is advisable for each simulation experiment to define how many repetitions of a simulation experiment should be completed – for a particular level of trust – in order to estimate an approximate average result of simulation (expected value). We deal with the use of the Monte Carlo method with reference to simulation results.

3. The use of simulation results in the decision-making process in air defense

Depending on its objectives, the simulation results might be various parameters obtained on the basis of difference

between initial combat capabilities and combat assets taken into account in the scenario and the final state (they might be losses of particular aircraft types, rocket air-defense systems, radiolocation stations on either side, effects of an attack on opponent facilities, etc.). Each partial simulation result might be treated as a random variable with its own distribution in the first numerical distribution. Normal distribution of a random variable might be accepted when its realization is influenced by many factors and that influence is unspecified and none of the factors has a dominant role. Consequently, we might deal with many random variables in a normal distribution, where the parameters of each of them are usually different. It can be assumed that the parameters of these distributions will depend, in a way difficult to establish by means of analytical methods, on the scenario and specificity of a simulator. As a result, it is necessary to identify the parameters of these distributions by means of statistical methods for each random variable of a scenario. It should be pointed out that the expected, the most probable result, not one of the possible results, is taken into account (on the basis of the results of such simulation). This is the essence of the probability attitude in consideration concerning the estimated effects of actions – nothing better has been invented so far. The most probable result of a random variable in a normal distribution refers to an average value (expected one) [3].

Another significant parameter is variable (or, e.g. standard deviation), which is the measurement of random variable dispersion. In anticipation of what might happen – what the only realization of random variable will be like – assuming that it will be the expected value, the greater "risk" of error we take, the larger dispersion of random variable realization is, that is the higher value of variable (standard deviation) characteristic of its distribution[3]. Commonly used units of dispersion are: a standard deviation, and variance of random variable (here, losses).

Assuming a normal distribution of losses, the following situation may be illustrated in the diagrams presented in picture 3.
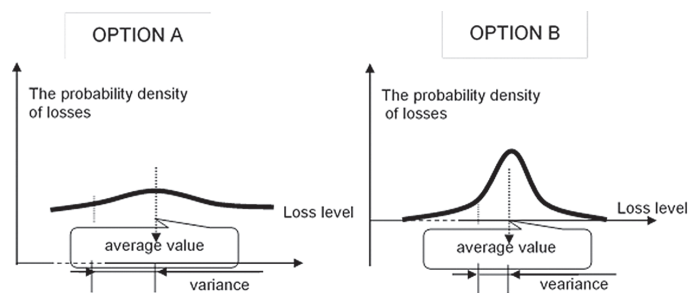
Picture 3. Distribution of losses for both variants.

Based on the example given in picture 2, it should be noted that the flatter Gauss's curve responds to a big variance (option A), hence a more hazardous situation. Variance is the measurement of the dispersion of consecutive realizations of options in the aspect of losses around expected values (average). The bigger dispersion (variance), the higher risk of obtaining the result different from what has been expected while

using a variant – estimated in plus or in minus [6]. Therefore, next to the criterion of the average efficiency value in assessing planning options in military operations, it is also essential to take into account the criterion of risk as its natural completion. Having access to simulation software and the scenario of operations, it is possible to estimate the selected random variable with assigned accuracy (there might be not only losses, but also any factor which accidently undergoes changes during simulation. The estimation of distribution parameters, which is an average value or variance for any random variables characteristic for a described option of operations is relatively easy while using simulation software designed for assessing fights/fighting?. It is always possible to mark the necessary number of simulation experiment repetitions, to estimate the value of these parameters by means of statistical methods [7]. The necessary number of experiments N to estimate the parameters of distribution with a given measurement error can be calculated using the following procedure:

1. Outlining relevant initial data of a given simulation (random variables).
2. Defining the value of error in units, in which initial data is measured e.g. in initial data, losses are in F-16, the error of average value assessment can be specified on any low level, it can be lower than units. Nevertheless, one should bear in mind that the smaller an error is, the more simulation experiments should be conducted to the estimate average (estimated) value of initial data.
3. Defining the level of trust for every output value, i.e., the probability that in estimating the average value one can make an error larger than the adopted measurement error. As we deal with the operational-tactical nature of making estimations while assuming values of trust levels, some analogies for accepting guaranteed probability values used in the past in efficiency calculations (0.95,0808) can be applied. Hence, for really significant values, it is recommended that the level of trust α would be 0.05; and for a smaller factor between 0.1 and 0.2.
4. Estimating the initial standard deviation δ (variance – δ) for each initial data. For this purpose, we conduct a series of preliminary simulations (e.g. 5–6) and we carry out a preliminary assessment of each selected initial data regarded as the result of a simulation [3]. If parameter regarded as the result of a simulation shows a substantial deviation from its average, the number of preliminary simulations should be increased e.g. to 12. For example, for data we receive a sequence of preliminary results $(x_1, x_2, \ldots x_1 \ldots x_n,)$, which allow us to calculate the value δ^2 on the basis of the formula below [8]:

$$\delta^2 = \frac{1}{n-1} \cdot \sum_{1}^{n} (\bar{x} - x_i)^2 \qquad (1)$$

where: an average value is calculated as an arithmetic mean on the basis of:

$$\bar{x} = \sum_{i=1}^{n} \frac{x_i}{n} \qquad (2)$$

We calculate the variance for each – unit selected as initial data as for data x.

We define the necessary number of simulations N. For this purpose, we calculate a number of experiments for each initial data on the basis of [8]:

$$N = \frac{\delta^2}{\varepsilon^2 \cdot \alpha} + 1; \qquad (3)$$

where:

δ – preliminary estimate of standard deviation (δ^2-variance) in point 4;

ε – expected error measurement in point 2;

α – trust level of calculations-probability of making an error bigger than estimated measurement error-ε, assumed in point 5;

For further consideration, we need to take the biggest number of repetitions of the simulation experiment which was derived from a number of repetitions for each initial data (N_max).

We conduct N_max experiments, and on the basis of their results, we calculate an average value and variance for each initial data as result of simulation on the basis:

$$\bar{x} = \sum_{i=1}^{N_{max}} \frac{x_i}{N_{max}} \qquad (4)$$

where: x_i result of i-experiment of data x.

$$\delta^2 = \frac{1}{N_{max} - 1} \cdot \sum_{1}^{N_{max}} (\bar{x} - x_i)^2 \qquad (5)$$

To sum up, conclusions including formulating an anticipated assessment with the use of the GAMBLER simulator in experiments involving aspects of efficiency of task fulfilment by means of combat assets requires preparation of statistical results of series planned simulations which might be conducted in compliance with a suggested procedure [9].
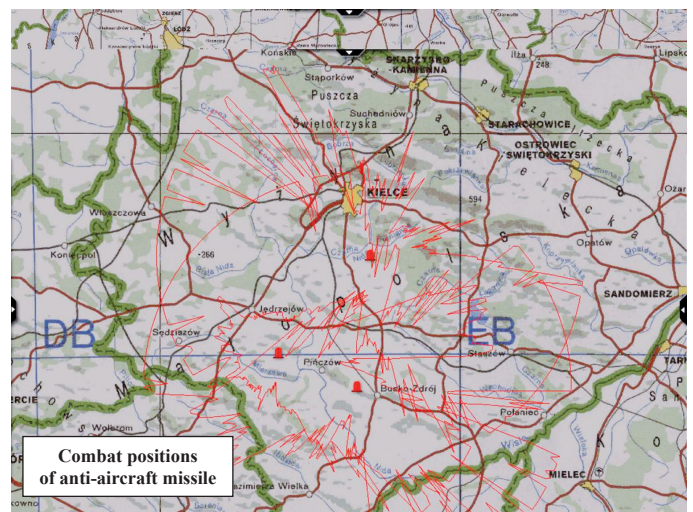
Picture 4. An example of depicting the deployment of missile defense systems on the monitor when modeling an air defense system at the tactical level.
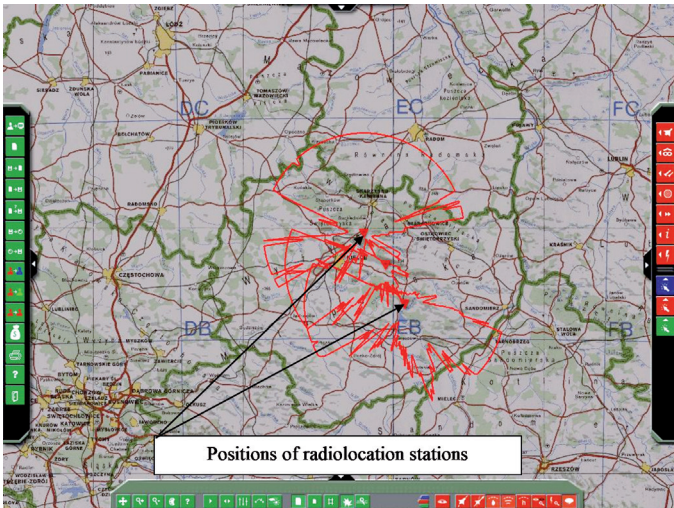
Picture 5. An example of the contents of the workstations depicted on the monitor during the modeling of the opponent's radiolocation information area (selection of positions of radars)

To sum up, conclusions including formulating an anticipated assessment with the use of the GAMBLER simulator in experiments involving aspects of task fulfilment efficiency by means of combat assets requires preparation of statistical results of series planned simulations which might be conducted in compliance with a suggested procedure [9].

In summary, it can be assumed that it is recommended to use the GAMBLER simulator to prove a doubted hypothesis [10]. For example, let us assume that a decision-maker has some doubts as to how to determine facilities for attack on air force for the following day. Furthermore, let us assume that he has two hypotheses of equal efficiency or with little dominance of one over the other, resulting from irrelevant, subjective preferences. The first one shows a legitimacy of attack of the C31 system (command and reconnaissance system), the latter – a need to stop air attack. Both groups of facilities are perceived as strong sides of the opponent. Proving one of hypothesis with the use of GAMBLER simulator is possible according to rules mentioned below such as [11]:

- the change of a single factor;
- transparency of sides' intentions;
- exclusion of a rare event or case;
- maintaining limited relations.

Attention should be paid to the fact that what will be anticipated is a situation which will occur not sooner than two days, which may raise problems with the opponent's assessment and necessity to take default decisions by commanders in the whole chain of command in air defense [12].

4. Conclusions

Precise descriptions of functional capabilities and rules of using a simulator are included in literature. Nevertheless, a synthetic description of its capabilities in this article should allow better understanding of it, especially in the context of its use in solving problems of command of air and ground facilities in air defense. The most important use of the simulator

in question in supporting a planning process conducted on commanding position of anti-aircraft missile brigade of air defense (SAMOC) is modelling a combat group in the Missile Engagement Zone – MEZ in order to create an appropriate system of fire and to recognize air opponents. Ways of using a simulator might vary here. Full verification of the legitimacy of simulator use presented in this article has been confirmed to some extent by its users, for whom this tool has been assigned. The use of the simulator to support the command of the air force was a secondary issue at the time of its construction. Attention was drawn to its application features in supporting task accomplishment and the possibility of its use during scientific research. However, the use of GAMBLER in command plays the most important role, not only due to its range of use and achieved effects, but mainly due to decisions taken in the decision-making process [13]. Yet, the possibility of raising them on a higher substantive level thanks to the use of the simulator, even in one of suggested solutions is enough to justify the need for its use in air defense command. It should be noted that from the technical point of view, the advantage of computer simulation as a method of research is its versatility and universality in considering various problems. It allows us to experiment, check and compare new systems or launch changes to systems already functioning.

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