
# Methods for System Analysis of the Operational Capability of Armed Forces for Defence Including Electronic Warfare

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# Agenda

- ✓ Brief intro
- ✓ The concept of Capability Based Planning
- ✓ Formal Model for CBP
- ✓ Allocation problem
- ✓ Methods of solution
- ✓ Experimentation environment
- ✓ Examples
- ✓ The conclusions

# Brief intro

- Armed Forces (AF) structure optimisation within defence planning processes
- The Military University of Technology team, taking part in the Polish Strategic Defence Review, has proposed a set of computational methods and tools in order to support the analyses for the evaluation of the required capabilities of the Polish Armed Forces in a predicted security environment
- Model of a conflict that is specifically constructed for the allocation of Armed Forces' components based on the measures defined for dimensioning and testing the reference modules' capability to fire
- The method of allocation of the fire capability to respond to the threatening scenarios is based on our own specific method in the area of computational intelligence as well as optimisation theory.

# Brief intro

- We have tested different ways to evaluate the optimisation process. The capabilities' measures of weapon systems and some important parameters (like terrain or type of operation factors) are defined and presented.
- The presented method was implemented, tested and compared with other approaches.
- The application is a part of the System of Computer Based Support of Capability Development and Operational Needs Identification of Polish Armed Forces
  (Presenter of the paper was PM of the system)

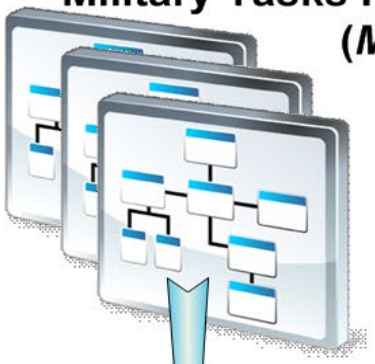
# Essence of CBP

- ✓ Operational needs should be defined in the context of capabilities, rather than systems assigned to individual types of armed forces, or armies.
- ✓ The new approach to planning assumes that the emergence of new threats does not necessarily automatically generate a need for new military equipment. It was intentional to answer the question, what needs to be done? This was concretely reflected in the intention, which can be described by replacing the phrase we need better combat aircraft with the statement we need the ability to overpower the enemy in the airspace. The formulation edited in this way not only clarifies and justifies operational needs, but also allows for creative concepts for new system solutions in terms of how to acquire capabilities and even compete among them.

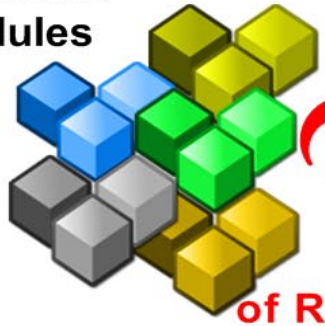
# Planning, Programming and Budgeting Process

Planning Scenarios

Reaction Scenario – Military Tasks Realization Network (*MTRN*)



Reference Modules

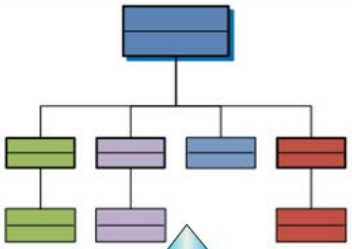


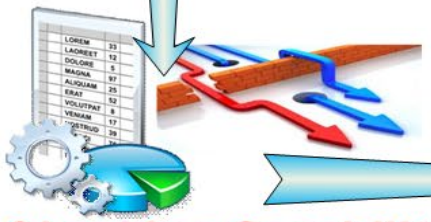
Optimal Allocation

*MTRN*

Estimation of Required Capabilities

Model of Armed Forces





Assessment of Lacking Capabilities and Identification of Needs

Simulation Assessment of Options for Obtaining Capabilities

# Threat Analysis for the Development of Planning Scenarios

**Types of Threat:**

- ✓ Terrorism/terrorist attack;
- ✓ Proliferation of weapons of mass destruction and their means of delivery;
- ✓ Threatened security of supply: energy, information, other types of goods (related to attack on critical infrastructure, transport and communication routes, cyber-attack, etc.);
- ✓ Hybrid threats;
- ✓ Threats of large-scale conflict.

**Planning scenario parameters:**

- ✓ The location of the threat: inside the country, outside the country but within the EU and NATO territory, outside the EU and NATO territory;
- ✓ The source of the threat (state/non-state actor, individual/group/organization, nature);
- ✓ Nature of the incident: terrorist attack/aggression/disaster;
- ✓ Nature of weapon used: attack with conventional/non-conventional weapons;
- ✓ Space: land, water, air, cyberspace, (and/or cyber-electromagnetic space);
- ✓ Scale and impact: city/region, country, group of countries, number of casualties.

# Concept of Operations (CONOPS) – Reaction Scenario

- ✓ CONOPS is an idea, a general plan that can be transferred into an operational context. Thus, concepts illustrate how armed forces conduct operations (will conduct operations). They describe what capabilities are needed to conduct the full spectrum of missions and to counter potential adversaries, in the expected operational environment. They explain how the commander, using operational art and possessed capabilities, achieves the intended effects and strategic objectives.

# The main concepts

- Operational Capability - the potential for efficiency with the possibility of an entity resulting from its characteristics and properties, allowing for an action to achieve the desired effects;
- The components of functional operational capability -
  - the doctrine, organisation, training, military equipment, personal resources, leadership, infrastructure, interoperability;
- A carrier reference capacity - an abstract object that corresponds to a single copy of military equipment (e.g., tank, armoured vehicle) or a group of such equipment that makes up the system (the system of radio communications, missile launcher);
- A measure of the capability to fire at targets of a specific type of intensity to destroy those targets - understood as the expected value of the number of targets of a specific type in a fixed unit of time

# Reference module

- The reference modules might be prepared by military analysts considering the prospective conditions of a battlefield. In essence, a reference module is related to a battalion.
- Mathematical model of reference module:

$$RMd_{F(E)}(i) = \left( \overline{n}_{F(E)}(i) = (n^{w}_{F(E)}(i))_{w \in W_{WS}}, \overline{MCP}_{F(E)}(i), AMC_{F(E)}(i) \right)_{i=1,..,N^{F(E)}_{RMd}}$$

$N^{F(E)}_{RMd}$ - number of types of reference modules for side F – the friendly forces (for side E – the enemy forces)

- $\overline{MCP}_{F(E)}(i)$ - vector of combat potential general and different categories of the reference module type $i$ of side F(E);
- $AMC_{F(E)}(i)$ - annual cost of the reference module type $i$ of side F(E).

$W_{WS} = \{1,..,N_W\}$ the set of number of types of weapon system

# Model of radio-electronic warfare

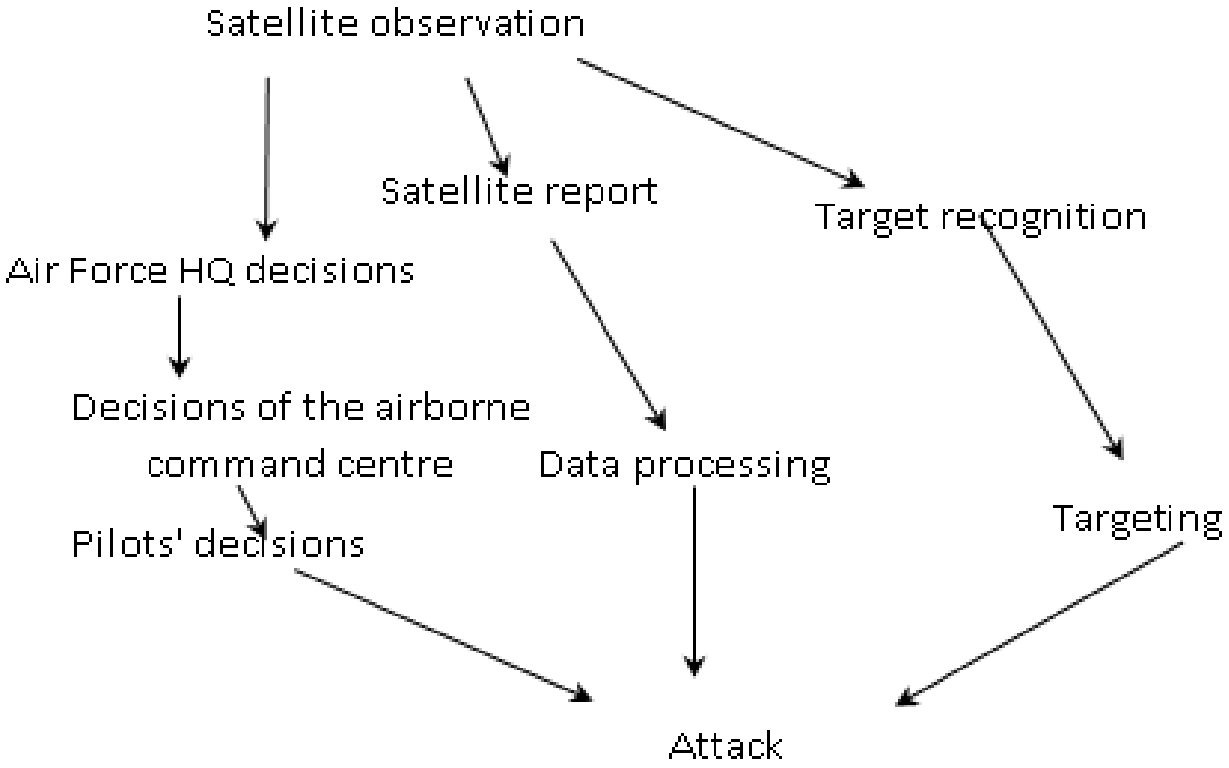
- ✓ Let's assume that :
- area with objects of military significance (along with their characteristics) is defined;
- radio-electronic warfare means are deployed around these facilities;
- groups of aerial attack measures (AAM) can carry out raids on covered facilities;
- aircraft, which are part of AAM groups, are equipped with various types of navigation, target detection and guidance systems for attacking them, and these devices and command posts (both land and air) are linked to each other through a hierarchical communication network;
- application of EW measures can introduce perturbations in the operation of this network.

# Model of radio-electronic warfare

- As a measure of the quality of the impact of EW measures, we take the time that elapses between the moment a group of AAM enters the zone protected by the air defence system and the moment the bombers start bombing or firing air-to-ground missiles toward our facilities.
- This time is the resultant of the execution times associated with recognizing the target, processing the data obtained about the object and its surroundings, and deciding whether to fire at the target.
- We assume that each of the task execution times is a random variable.
- Using jamming, it is possible to influence the extension of these times in terms of selected probabilistic characteristics (e.g., the expected value of time, quantiles of different orders of this random variable) and to make it more difficult for a group of AAMs to detect and destroy a ground target.
- The increment of this time to the first firing or bombing is the basis for comparing different interference plans (different allocations). Several stages can be distinguished in the engagement of elements of the AAM group during the execution of a raid.

# Model of radio-electronic warfare

Illustration of the increasing involvement of air force elements performing air-to-ground attack




The mission of an AAM group is to seek out and fight high-value targets (airfields, command posts, missile launchers, etc.). On the other hand, the purpose of planning the impact of radio-electronic warfare means is to "control" the **build-up** of engagement of the attacking AAM group during the execution of the raid. In other words, the goal of the **EW** is to make it difficult or impossible for elements of the AAM group to perform certain actions in the process of reconnaissance and target guidance before executing the final attack (dropping bombs or launching missiles).

# EW influence on enemy potential

- ✓ Electronic Countermeasures (ECM) involves the use of jamming and other techniques to disrupt or disable enemy communication and sensor systems. For example, ECM systems can use high-powered RF signals to overwhelm enemy radar, making it difficult for them to detect and track friendly aircraft. Using a variety of interference techniques, EW means can cause the following effects in the operation of radars, communication channels and data transmission line:
- ✓ slowing down the performance of target recognition and information transmission tasks;
- ✓ reduction in the scope of recognition;
- ✓ confusing aircraft pilots;
- ✓ to prevent the reception of data transmissions to elements of the AAM group carrying out a raid from the airborne command centre;
- ✓ the need to use two or more beacons (or other types of reconnaissance equipment) at the same time, to detect and identify attack objects

# EW influence on enemy potential

- A model was constructed to support the impact of EW measures operating in the defence system. The model is based on a stochastic network with arcs of random length. A similar model was presented in [14] to show how to determine integrated air defence system (IADS) quality measures. Elements of the model presented in [14] were used to solve radio battle planning tasks. The use of an extended, stochastic, activity network as a model of the functioning of the raiding party proved to be effective from the point of view of determining the characteristics of the radio-electronic warfare system.
- The results obtained in this way can give estimates of selected characteristics of the battlefield, in the introduction it was mentioned that it would be possible to show the influence of other defence elements on the outcome of the battle such as the activity of radio-electronic warfare means.
- Due to the lack of physical destruction of combat means during radio-electronic warfare, the problem of assessing the effects of active and passive interference against the electronic devices of these means should be approached quite differently from the assessment of the performance of missile troops, aviation and other fire means.

# EW influence on enemy potential – two ways

- In the first approach, the essence is to take into account the deviation of AAM trajectory and faulty guidance by navigation and bombing means depending on the intensity of jamming emitted by the jamming stations affecting this target, resulting in correspondingly lower losses of the bombed object. A characterization under the name of the probability of not destroying a ground object using directed radar interference is given there.
- In the second approach, a raid model is considered in the form of a network with arcs, which are assigned random variables describing the durations of the activities performed by the electronic devices of the AAM group. The effect of interference is to change the duration of activities in the sense of the distribution of random variables, and only those activities that are on the critical path that is, ultimately, the time to the first firing (bombing), performed by the AAM group, which is a measure of the quality of the interference.
- In both cases, the proposal for estimating the impact of EW reference modules on enemy air forces is based on conducting a series of simulation experiments with a planning scenario without EW impact and as many experiments with EW and examining the difference in losses inflicted on our side. The resulting estimate should result in a proportional reduction in the opponent's air force potential obtained in the general scenario (in the task of allocating reference modules).

# CI in allocation

- The idea of allocation based on computational procedure, which can be concerned in three aspects:
  - the knowledge is represented by numbers (characteristics of weapon systems and cost of military units exploitation),
  - knowledge processing is based mainly on numbers and
  - the knowledge of combat processes and budgetary conditions, are not represented explicitly (the knowledge is acquired in the simulation process)

Military tasks network – reaction scenario

$$S_p = \langle G, TT \rangle$$

$G = (NTT, U)$ directed graph

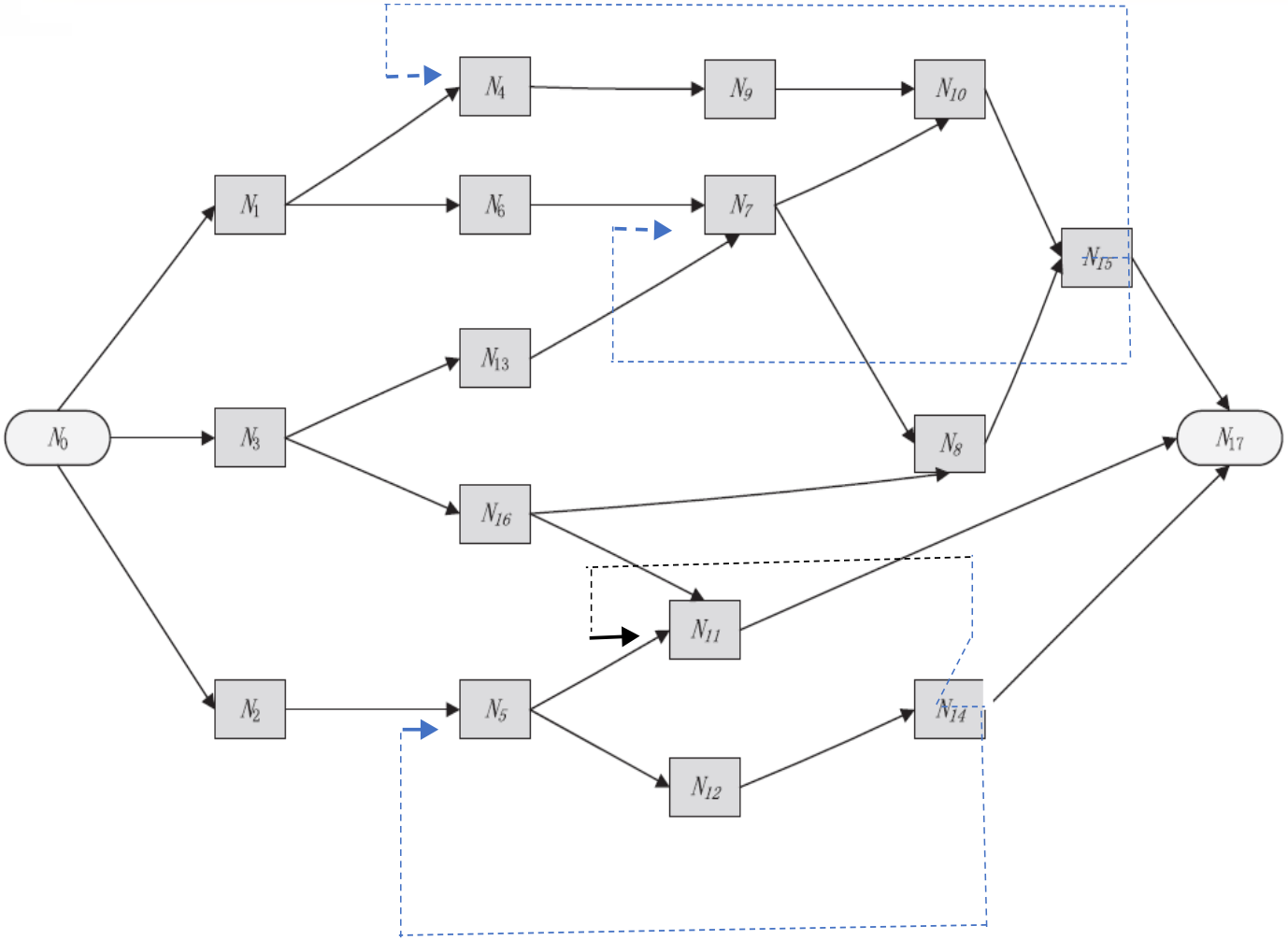
$NTT = \{1, .., N_{TT}\}$ set of military tasks

$U \subset NTT \times NTT$ set of arcs which represent precedence relations between military tasks - a task must not start until all its predecessors are finished

$TT = \{type_{tt}(\bullet), t(\bullet), \tau(\bullet), Env_{tt}(\bullet), OPFOR_{tt}(\bullet), EF_{tt}(\bullet)\}$

set of functions defined on the nodes of the graph

# Military Task Network




Possible relationships between the tasks, not only sequential ones. The number of modules assigned to a positional defence task (later tasks) will require the assignment of a certain number of transport modules in a transport task (the earlier task). The sequence relationships are indicated in the figure by a continuous line. The feedback dependencies (from later tasks to former tasks) are marked with a dashed line.

# Decision variable of allocation problem

**X =**

| | Modules for command | | | | | Modules for reconnaissance | | | | | Modules for fire (striking) | | | | | Modules for saving and surviving | | | | | Modulse for logistics | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Typ 1 | Typ 2 | ... | Typ m-1 | Typ m | Typ 1 | Typ 2 | ... | Typ n-1 | Typ n | Typ 1 | Typ 2 | ... | Typ k-1 | Typ k | Typ 1 | Typ 2 | ... | Typ l-1 | Typ l | Typ 1 | Typ 2 | ... | Typ p-1 | Typ p |
| Task 1 | 8 | 4 | | | | | 2 | | | | | | 1 | | 2 | | | 2 | | 6 | | | 7 | | |
| Task 2 | | 3 | | 4 | | 9 | | 3 | | | 4 | | | | 3 | | | | | | 7 | | | | 6 |
| Task 3 | | | | 5 | | | | | 1 | | | | | 7 | | | 8 | | 3 | | | 3 | | | |
| Task 4 | 6 | 9 | | | | 1 | | 3 | | | 2 | | | 6 | 5 | | | 4 | | | 3 | | 2 | | 4 |
| Task 5 | | | | | 2 | | | | 2 | | | 9 | | | | | 2 | | 5 | | | 2 | 1 | | |
| ... | | | 2 | | | | 3 | | | | 1 | | | | 2 | | 1 | | | 7 | | | | 9 | |

**$T = [T_k]_{k=1..lz}$ – start times for tasks realization**

# Allocation problem

Multi-criteria optimisation problem:

To determine $\left(\bar{X},\bar{T}\right) \in \overline{XT}_N^{\leq}$

$$Z_{AMK} = \left(XT, F, \leq\right)$$

$$F\left(\bar{X},\bar{T}\right) = \left(F_1\left(\bar{X},\bar{T}\right), F_2\left(\bar{X},\bar{T}\right), F_3\left(\bar{X},\bar{T}\right)\right)$$

(cost of exploitation, cost of acquisition, personnel losses)

$XT$ vectors $(\bar{X},\bar{T})$ that meet the following conditions:

$$\leq = \{(y,z) \in R^3 \times R^3 : y_i \leq z_i, i = 1,2,3\}$$

$$x_{m,z} \in \{0,1,2,...\}, m = 1,..,\overline{MK}_A, z = 1,..,\bar{N}_{TT}$$

Restriction set W:

- own losses may not exceed the limit;
- the losses of the opponent must not be less than the limit value;
- the ratio of the own power potential and the opponent's power must not be less than the limit value;
- the ratio of the sum of the potentials of own forces (tanks of medium and long-range anti-tank means) to the sum of the potentials of tanks, armoured transporters and combat vehicles of enemy infantry forces must not be less than the limit value;
- the ratio of the potential to arm the enemy's own air defence forces to the potential of the enemy assault helicopters must not be less than the limit value,

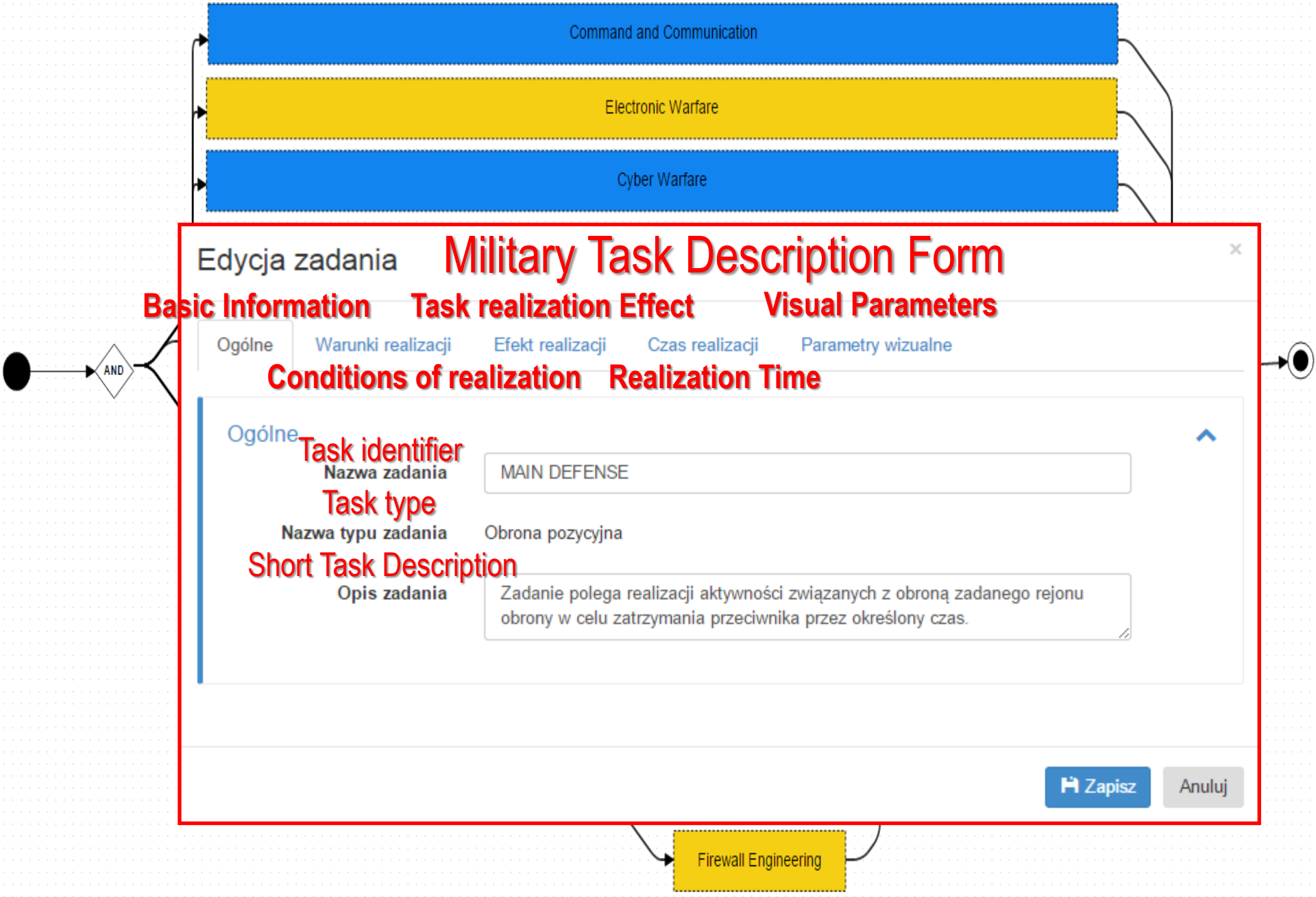
# Simplified allocation problem

$$\min_{\bar{X}_F}(k_1 F_1(\bar{X}_F) + k_2\ F_2(\bar{X}_F) + k_3\ F_3(\bar{X}_F));$$

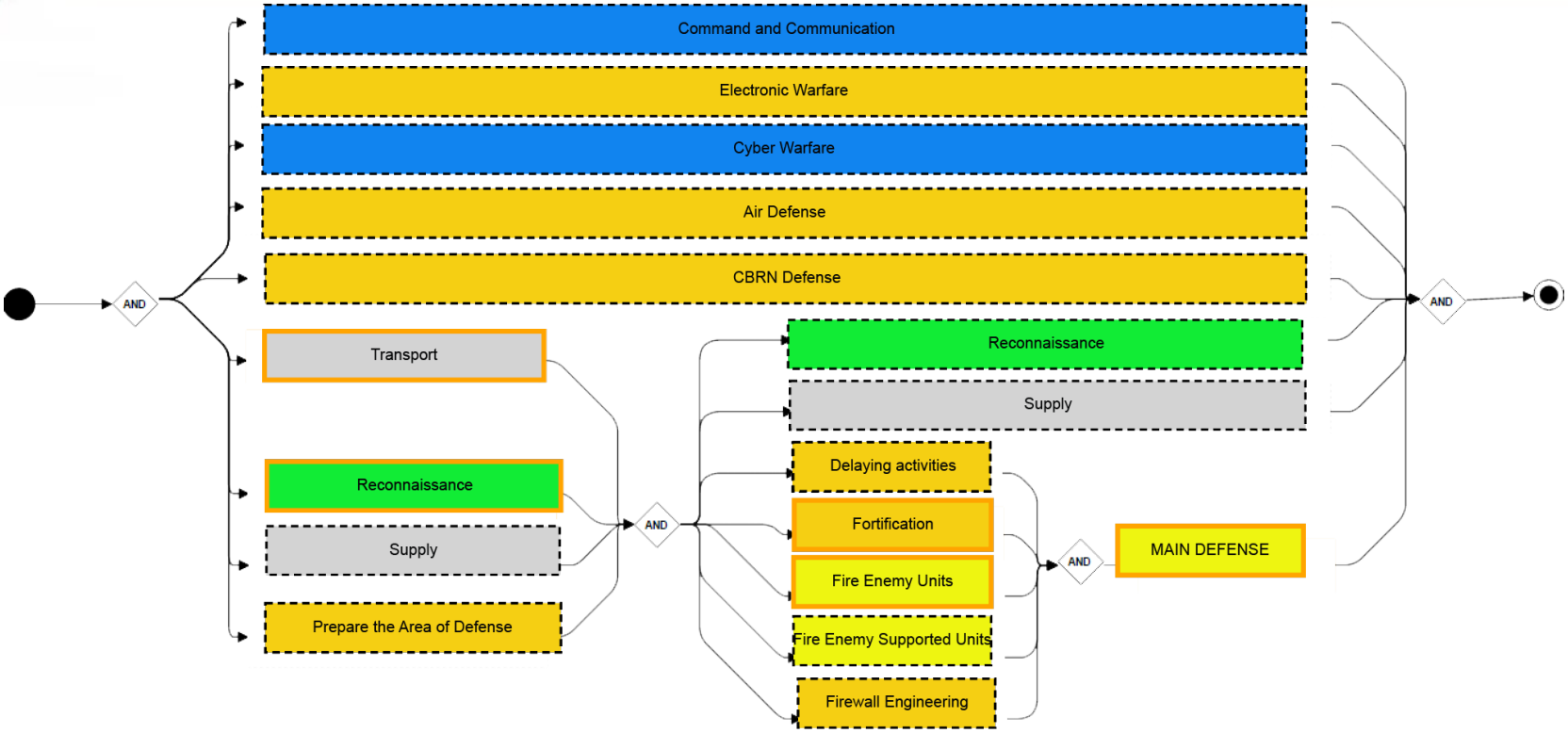
$$k_1 + k_2 + k_3 = 1 \wedge k_1 > 0 \wedge k_2 > 0 \wedge k_3 > 0$$

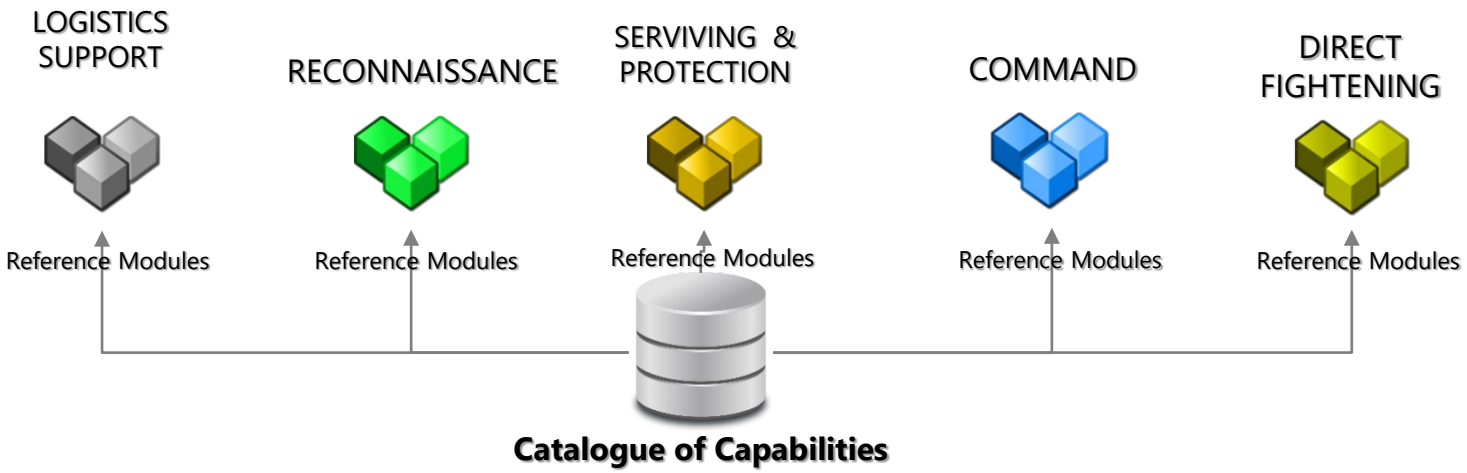
- ✓ With the restriction set W

# Experimentation environment

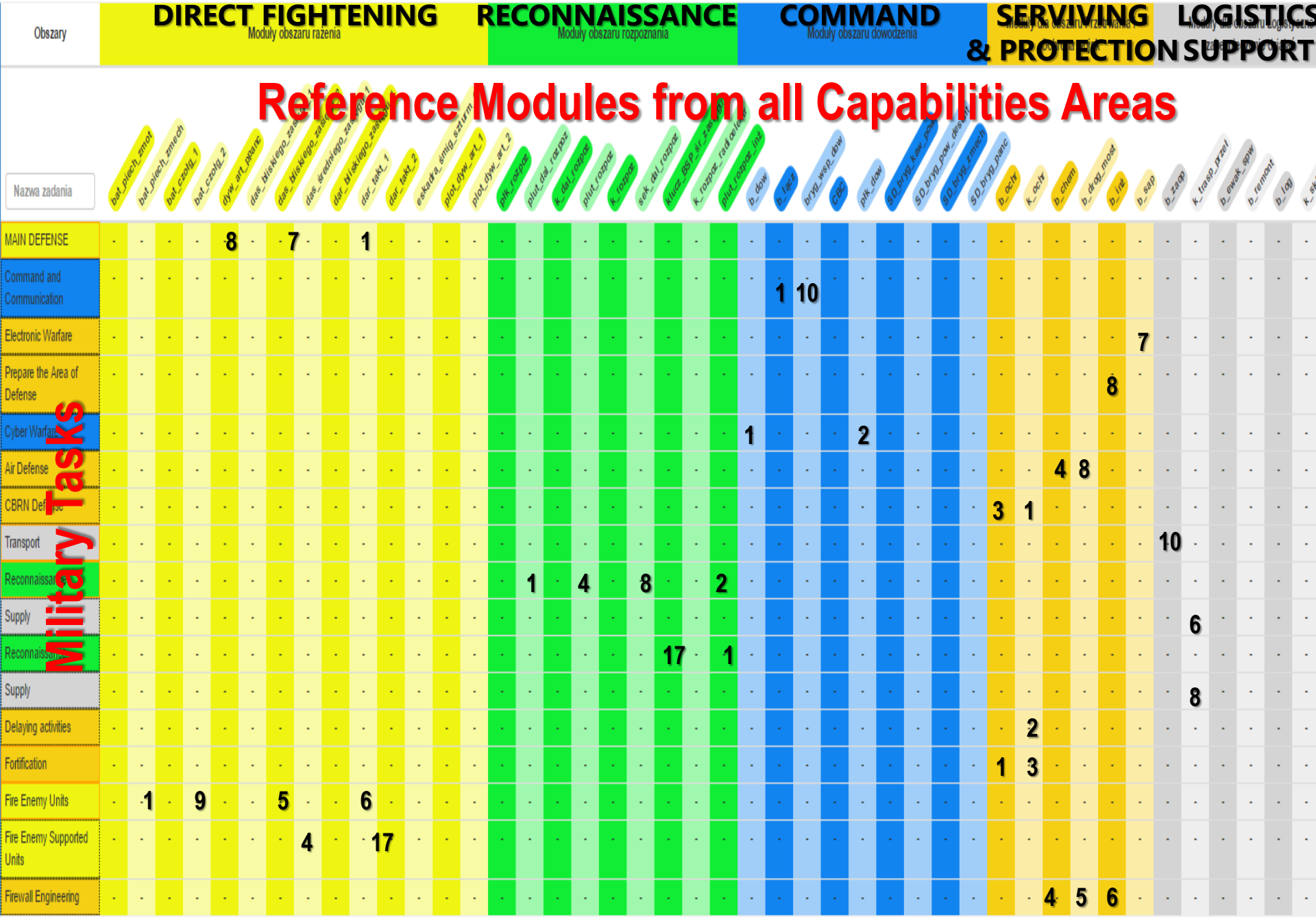


# The idea of capability allocation



# MATRIX - The result of allocation



# Experimentation

| | The parameters of attack rate function | | | |
|---|---|---|---|---|
| | Hasty defence | | Deliberate defence | |
| L=0,95 | a | b | a | b |
| GO | 0,999 | 0,612 | 0,607 | 0,581 |
| SLOW GO | 0,521 | 0,846 | 0,455 | 0,545 |
| NO GO | 0,406 | 0,567 | 0,167 | 0,819 |

Combat rates and terrain parameters

$$V(R) = a \cdot R^b$$

$$R_t(B, A) = \frac{Val_B(t)}{Val_A(t)}$$

| | Hasty defence | | | Deliberate defence | | |
|---|---|---|---|---|---|---|
| R | GO | SLOW GO | NO GO | GO | SLOW GO | NO GO |
| 1 | 1 | 0,5 | 0,4 | 0,6 | 0,5 | 0,15 |
| 2 | 1,5 | 1 | 0,6 | 0,9 | 0,6 | 0,3 |
| 3 | 2 | 1,3 | 0,8 | 1,2 | 0,75 | 0,5 |
| 4 | 2,4 | 1,75 | 0,9 | 1,4 | 1 | 0,6 |
| 5 | 2,6 | 2 | 1 | 1,5 | 1,1 | 0,6 |
| 6 | 3 | 2,3 | 1,1 | 1,7 | 1,3 | 0,6 |

# Examples

- Scenario I:
- Enemy Forces (side B): 2 armoured divisions
- Weapons: 620 tanks, 310 armoured carriers, 628 artillery guns, 60 helicopters, 120 guns and missile launchers of air-defence.
- The importance of the cost criterion - 0,5, importance of criterion personnel losses - 0,5 we have received the modules allocation for a “deliberate, position of defence”:


## Allocation of reference modules, scenario I

| No | Type of module | AF Structure |
|---|---|---|
| 1 | Motorised Rifle battalion | 0 |
| 2 | Mechanised battalion | 4 |
| 3 | Armoured bat. generation 2 | 0 |
| 4 | Armoured bat. generation 3 | 3 |
| 5 | Antitank squadron | 1 |
| 6 | Artillery squadron (SR) 1 | 1 |
| 7 | Artillery squadron (SR) 3 | 0 |
| 8 | Artillery squadron (MR) | 1 |
| 9 | MLRS | 0 |
| 10 | Artillery squadron TM 1 | 0 |
| 11 | Artillery squadron TM 2 | 0 |
| 12 | Air defence squadron 1 | 0 |
| 13 | Attack squadron helicopter 1 | 0 |
| 14 | Attack squadron helicopter 2 | 0 |

# Results

| | Capability for striking held | | |
|---|---|---|---|
| **range** | armoured | fire means | personnel |
| **short** | 4107,46 | 4829,06 | 6758,10 |
| **medium** | 170,01 | 1386,84 | 1806,80 |
| | Capability for striking required | | |
| **short** | 1273,29 | 651,14 | 887,75 |
| **medium** | 66,59 | 558,91 | 734,23 |
| | The degree of held capabilities % | | |
| **short** | 322,59 | 741,63 | 761,27 |
| **medium** | 255,31 | 248,13 | 246,08 |

# Examples

- ✓ Scenario II
- ✓ Enemy Forces (side B): 5 armoured division
- ✓ Weapons: 1240 tanks, 620 armoured carriers, 1256 artillery guns,120 helicopters, 160 guns and missile launchers of air-defence.
- ✓ The importance of the cost of exploitation criterion - 0,5, importance of criterion personnel losses - 0,5 we have received the modules allocation for a “deliberate, position of defence”:

## Allocation of reference modules, scenario II

| No | Type of module | AF Structure |
|---|---|---|
| 1 | Motorised Rifle battalion | 0 |
| 2 | Mechanised battalion | 8 |
| 3 | Armoured bat. generation 2 | 0 |
| 4 | Armoured bat. generation 3 | 6 |
| 5 | Antitank squadron | 1 |
| 6 | Artillery squadron (SR) 1 | 4 |
| 7 | Artillery squadron (SR) 3 | 0 |
| 8 | Artillery squadron (MR) | 1 |
| 9 | MLRS | 1 |
| 10 | Artillery squadron TM 1 | 0 |
| 11 | Artillery squadron TM 2 | 0 |
| 12 | Air defence squadron 1 | 0 |
| 13 | Attack squadron helicopter 1 | 0 |
| 14 | Attack squadron helicopter 2 | 0 |

# Results - scenario II

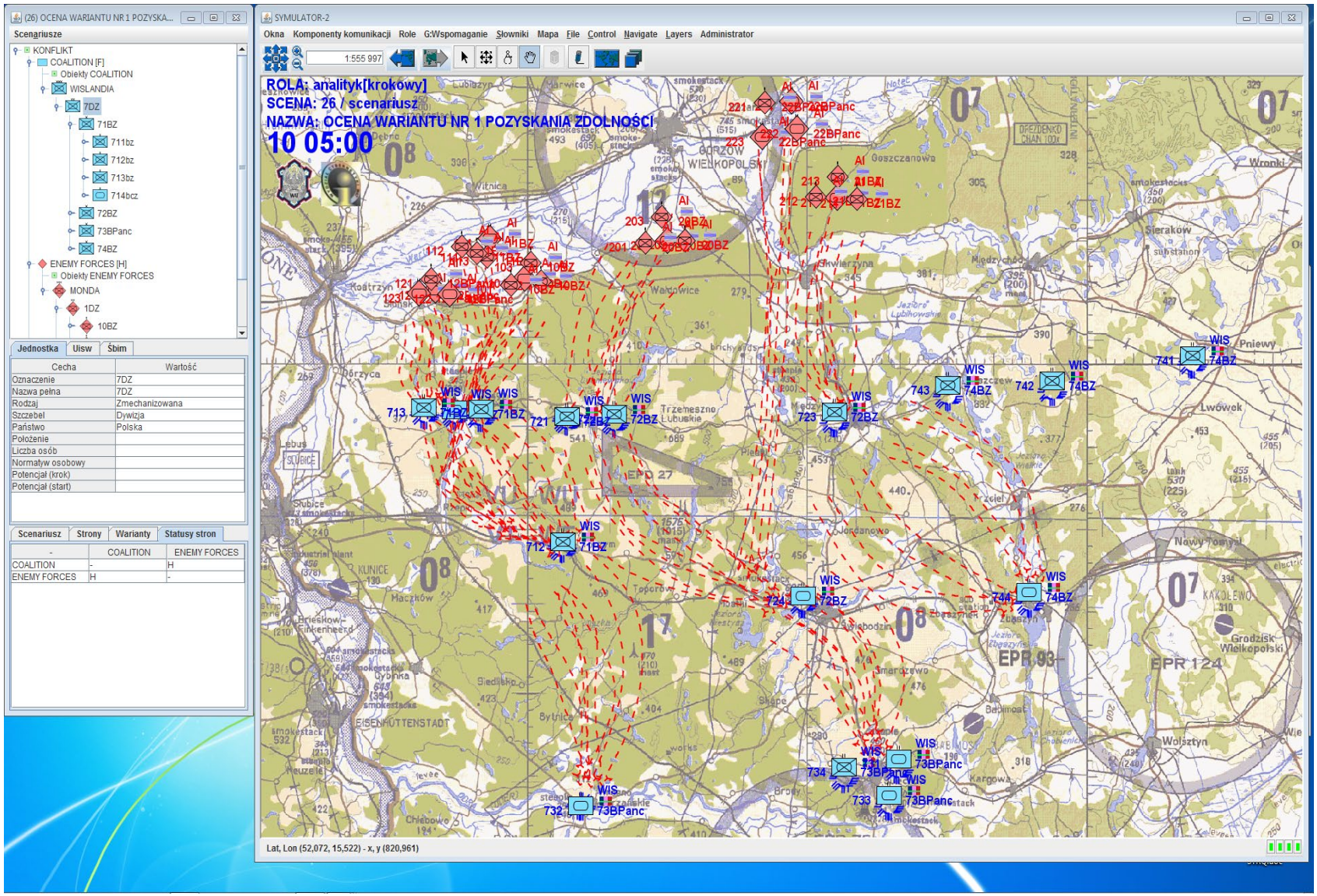
| | Capability for striking held | | |
|---|---|---|---|
| **range** | armoured | fire means | personnel |
| **short** | 4107,46 | 4829,06 | 6758,10 |
| **medium** | 170,01 | 1386,84 | 1806,80 |
| | Capability for striking required | | |
| **short** | 2555,12 | 1398,17 | 1910,58 |
| **medium** | 141,72 | 1213,71 | 1603,56 |
| | The degree of held capabilities % | | |
| **short** | 160,75 | 345,38 | 353,72 |
| **medium** | 119,96 | 114,26 | 112,67 |

# Simulation support for the CBP

## Simulation assessment of options for obtaining capabilities

- For a fixed option for obtaining operational capabilities (with respect to all defined planning situations), using simulation model, values for given criteria are calculated:
  - loss of capability,
  - the cost of losing the capability,
  - level of completeness of the mission,
  - probability of the mission success.
- By calculating values for given criteria for different options for obtaining operational capabilities, it is possible to choose the best one.

# Combat Simulator



# The conclusion and recommendations

1. The idea of a qualitative and quantitative support method for Capability Based Planning of Armed Forces development was presented;
2. The paper presents the idea of obtaining the capabilities of the armed forces, including in the selected area of electronic warfare capabilities;
3. It provides a contribution to conducting analysis of military operations in a multi-domain environment;
4. The current problem is to develop a method for studying the impact of emerging and disruptive technologies (EDTs) on specific AF capabilities, and this includes developing a method for mapping emerging and disruptive technologies to capabilities in strike (jamming), command, battlefield protection, reconnaissance and logistics by functional capability component;
5. From this emerges the need to identify specific operational capabilities and combat domains in which EDTs will be relevant, a description of methods for dimensioning operational capabilities according to their functional components - a description of metrics and methods for their determination in order to assess the impact of EDTs on these capabilities.