Computer Simulation of Armed Mobile Platform Group Swarming*

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Abstract- **The research of swarming – the tactics which has more and more been taken into account in modern combat activities conceptualizing – is underway. Adaptation of armoured and mechanized units for swarming could be the best investment in technically inferior armies' modernization. Brief survey of the so far research and the results of experiments simulating swarming of the group of armed mobile platforms, defending territory from numerically and technically superior adversary unit, have been considered in the paper.**

Key words **- simulation, swarming, armed mobile platform, group, armoured battalion**

I. INTRODUCTION

The aim of this paper is to present some of the results of the research of armoured and mechanized units swarming, which is underway at Union University School of Computing in Belgrade, Serbia.

Swarming [1] is a tactics by which military forces attack an adversary from many different directions, and then regroup. Repeated actions of many small, manoeuvrable units are going on, circling constantly through the following four phases of *swarming*:

- Disperse deployment of units in battlefield;
- Gathering (concentration) of many units on common target;
- Action (strike or fire) at a target from all directions;
- Dispersion of units.

The way of swarming application is depicted in figure 1, and its basic characteristics have been given in Table I.

Although numerous examples of successful swarming application have been recorded in history [2], the significance of this tactics did not reach its full measure until our days, due to brisk development of information technologies and merging of computing and telecommunications.

The swarming tactics is applied by (numerically) much smaller units, but their use is far more efficient, so in their actions as a whole, they can often defeat many times superior adversary.

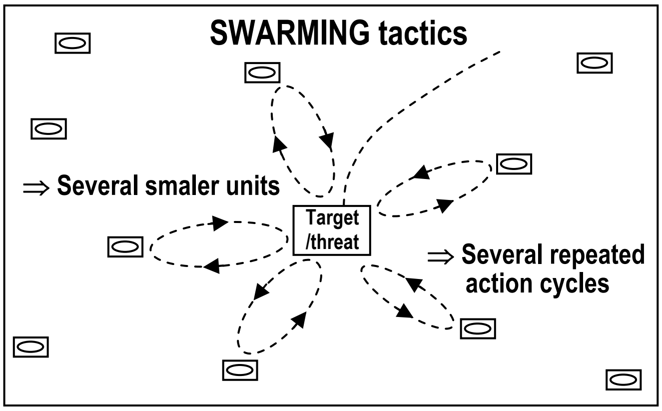

Fig.1 Swarming of armoured and mechanized units against target/threat

TABLE I
SWARMING: BASIC CHARACTERISTICS

➢ Autonomous/semiautonomous units, engaged in concentrated attack at common target
➢ Amorphous, but coordinated attack from all directions by continuous "pulsed" fire/shock assaults
➢ Many small, space dispersed mutually networked units.
➢ Integrated surveillance, sensors, and C4I systems for upper level situation assessment.
➢ Units' action capabilities, from distance as well as in direct contact.
➢ Continuous attacks with aim of breaking adversaries' cohesion.

Adaptation of armed forces for swarming, existing armoured and mechanized units in particular, could be one of the best investments for small countries and their armies, as it is the case with Serbia [3]. That is the basic motivation for the research of swarming at Union University School of Computing in Belgrade, Serbia.

Firstly a brief survey of the so far research has been given in the paper, and then presentation of the model. After that, the results of the experiments executed by means of the realized simulator have been analyzed.

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Swarming of the group of armed mobile platforms against one target/threat which suddenly appears in the defended territory with variable dimensions has been simulated.

Finally, there is a brief regard to limitations of the realized simulator and further research directions. The transfer to multitarget systems is expected, as well as different initial deployments of the AMPs group in such situations.

II. SOME RESULTS OF THE RESEARCH SO FAR

The approach to simulation of swarming, new tactics which members of armoured battalion, as a group of armed mobile platforms (AMPs) can apply in conflicts with numerically and technically superior adversary units has been presented in [4]. The approach of the research takes into account every single tank in the simulation, and the armed mobile platforms group is considered at the level of an armoured battalion.

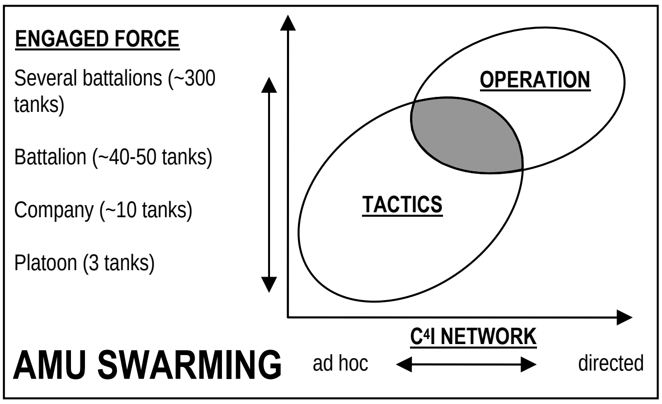

Fig.2 Armoured and mechanized units tactical and operational swarming

Armoured battalion has been chosen as target group of armed mobile platforms for simulation, having in mind that it appears in tactical, as well as in operation swarming level (Fig.2) of armoured and mechanized units (AMU).

Tactical actions are performed up to the level of battalion, but a swarming group forming is also possible taking into account all subordinate units, until every single tank. On the other hand, armoured and mechanized units, organized in such manner, can perform operation swarming, which involve more units than one armoured battalion.

The simulation model and the algorithm for the armed mobile platform group swarming (Fig. 3), implemented by means of the discrete events system simulation language GPSS World [7], have been presented in [5].

The realized simulator of swarming, which members of an armoured battalion, as a group of armed mobile platforms, can apply in conflict with numerically end technically superior adversary units (threat/target), has been presented in [6]. For the sake of testing the simulator, the experiment has been executed, with the system which characteristics are provided in Table II.

TABLE II
SIMULATED SYSTEM CHARACTERISTICS

Territory	20 km x 20 km
Threat/target velocity	$V_{t/t}$ = 15 m/s
Initial position	(0, 0) [m]
Final position	(20000, 20000) [m]
Threat motion law	Uniform, rectilinear, $V_{t/t}$
Number of AMPs	N = 43
AMPs initial deployment	Random, whole territory
AMP-*i* velocity	V_{AMP-i} = 15 m/s
W-*i* weapon	A = 1, D = 2500 m, U = 0.15
W-*i* cumulative effect threshold	PKU = 3 (20 AMPs needed for successful swarming)
C^4I system report period	Δt = 10 s

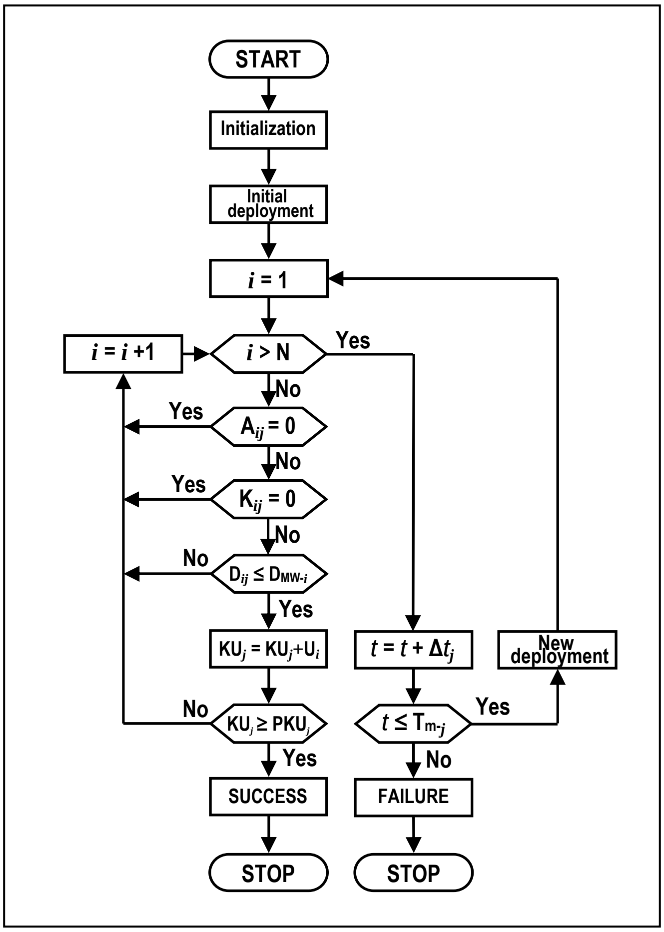

Fig.3 Swarming simulator basic algorithm

The simulator output in some characteristic moments of the swarming dynamic development has been graphically presented in Fig. 4.

One can see that AMPs of armoured battalion attained successful swarming (20 among them simultaneously have found themselves inside the curve representing boundary distance to threat/target of 2500 m) in t = 480 s, i.e. 8 minutes of simulated time after first detection of the adversary in the territory – theatre of the combat actions. As the mission time of the threat/target unit – to reach the point with coordinates (20000 m, 20000 m) – has been T_m = 1885,618 s in the case considered, the armoured battalion units in the presented experiment realization have successfully applied the swarming tactics in territory defending.

In [6], some results of the experiments with the realized simulator have been presented. The experiments have been executed in order to explore the impact of 3 different kinds of threat/target units and the defended territory dimensions on the swarming success of the group of N = 43 randomly deployed armed mobile platforms.

III. THE SIMULATED SYSTEM

The system being simulated consists of: one group of N armed mobile platforms (AMP-i, where i = 1, ... N), one threat/target unit (T), C^4I system and the defended territory – the theatre of combat actions (swarming).

Armed mobile platforms AMP-i, can move at velocities V_i. Each of them has main weapon (MW-i), characterized by range ($R_{MW\text{-}i}$) and compatibility with threat/target unit (K_{ij}), which determines its total effect in swarming against every threat/target unit (U_{ij}).

Every AMP is active member in the C^4I system and disposes appropriate equipment (GPS receiver, computer and radio transceiver for data transmission at speed V_{RU}).

Threat/target unit can move at maximal velocity $V_{t/t}$. It is superior to every single AMP of the group, so for the successful swarming it is necessary that the critical cumulative effect of several AMPs, specific to such threat/target, should be exceeded.

The primary function of the C^4I system is regular informing of every user on its actual position and other data of interest:

- about the threat/target unit, based on the data acquired by the territory multisensor surveillance network, individual AMPs of the group and other friendly forces;

- about every single AMP of the group, based on the regular reports of the AMP -i about changes in its own position.

C^4I system works successfully if it dispatches regular reports about threat/target unit and every single AMP-i motion before their expirations. Time of expiration of the report about every threat/target unit or AMP of the group is defined by the expression:

$$t_{\exp-i} = \frac{P_{C^4I-i}}{V_i} \qquad (1)$$

where P_{C4I-i} [m] is the preciseness of the C^4I system (prescribed relative distance from the previous known position, due to further motion, which can be tolerated as no motion at all), and V_i [m/s] is its velocity in the period of the report.

Combat actions take place in territory which is presented in the model by means of two-dimensional rectangular coordinate system.

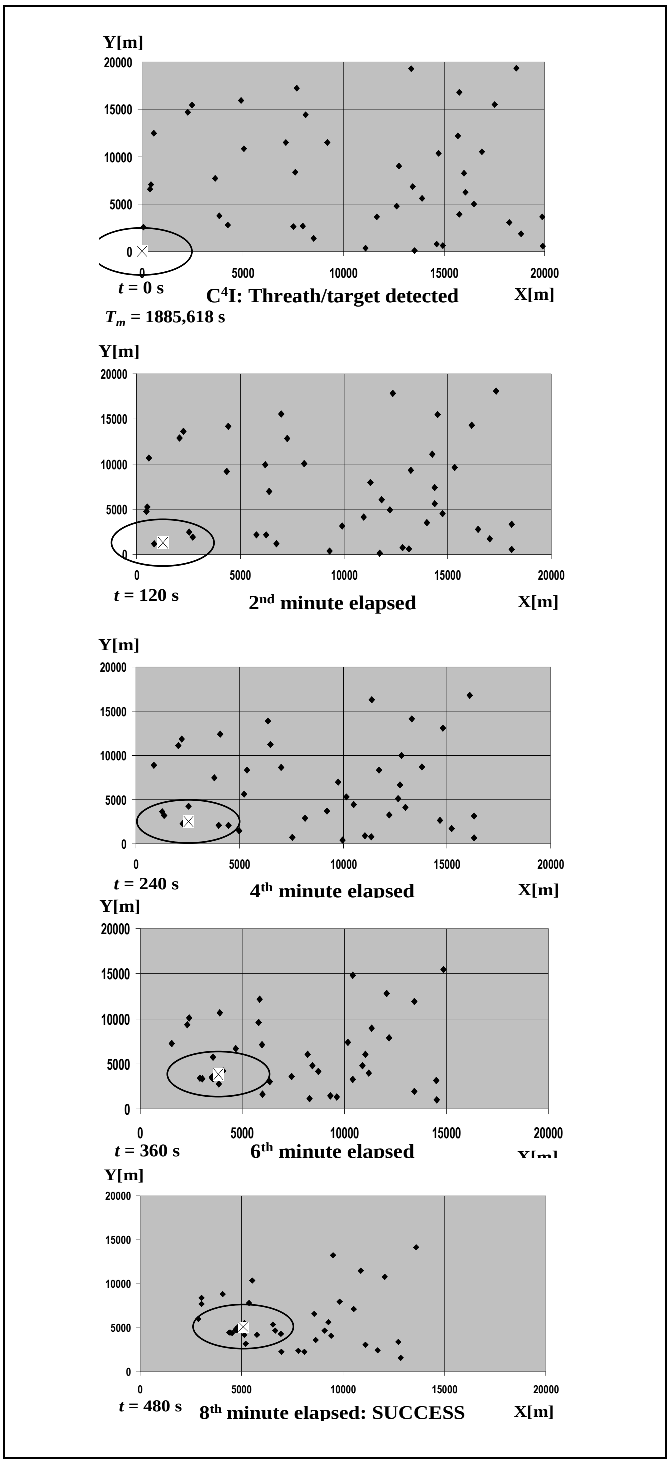

Fig. 4 Swarming dynamic development

IV. THE SIMULATION MODEL

The simulation model of the AMP group swarming is discrete and dynamic, oriented to events. In the model, system activities are represented by pure time delays.

The moving entities in the model are: units forming the group (AMP-i, i = 1, 2,…, N), threat/target unit (T) and messages of the C^{4}I system.

The initial deployment of the group of armed mobile platforms is random, which is the worst case, because the occurrence of threat/target is unexpected, and the AMP group is prepared for it by no deployment intended for defending territory under such specific circumstances.

The simulation goal is to explore impact of the variable defended territory occupancy density by the AMP group to success of its swarming. It has been achieved by changing the dimensions of the territory in experiments, along with retaining fixed number of AMPs in the group.

In the simulation, the group of the armoured battalion size has been considered, consisting of 43 armed mobile platforms (tanks, armoured personnel carriers, etc.).

The armed mobile platforms of the group (AMP-i) get information of the threat/target units and other AMPs of the group motion in time expiring intervals Δt, and give reports about their own current positions.

Based on that information, the armed mobile platforms, AMP-i, direct themselves toward threat/target unit, with the goal to reach, as soon as possible, the position enabling them to perform successful swarming, for the sake of destroying, disabling, or preventing the adversary in accomplishment of its mission.

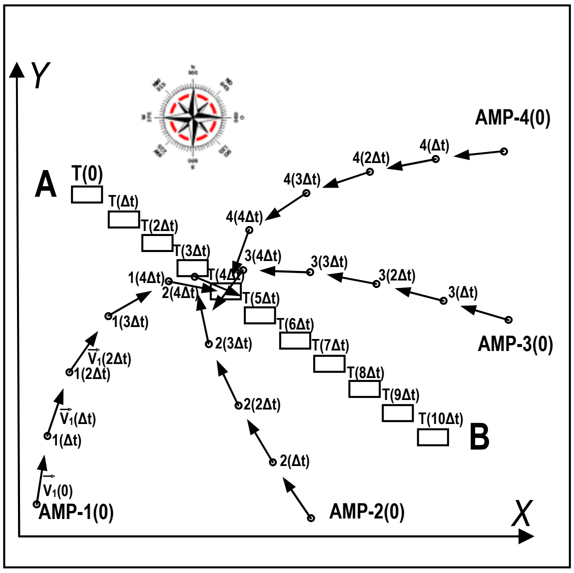

Fig.5 Motion of threat/target (T) and AMP-1, 2, 3 and 4

The graphical representation of motion of the part of the system, consisting of 1 threat/target unit (T) and 4 AMPs of the group (1, 2, 3 and 4), manoeuvring to accomplish the swarming is depicted in fig. 5.

The threat/target unit is accomplishing its own mission and, contrary to AMP-i, has no access to information of the C^{4}I system, so its primary goal is to fulfil its own task, which has been represented by motion on given trajectory between points A and B in the model, according to functional dependencies of its coordinates of time, $x_{t/t}(t)$ and $y_{t/t}(t)$.

When the period of expiration elapses and C^{4}I dispatches the report of the new threat/target position (t = Δt), threat/target has moved to its new position, T (Δt). Until then, AMP-i have moved to their new positions, 1(Δt), 2(Δt), 3(Δt) and 4(Δt), following the directions from the previous time interval, directed their velocity vectors towards new position of the threat/target, and then the process continues.

In order that individual swarming participating AMP-i could act upon threat/target unit, the following three conditions must be fulfilled:

a. AMP-i must dispose of the main weapon MW-i, compatible with the adversary unit.

b. The distance between AMP-i and the adversary unit j must be in the main weapon MW-i range limit, i.e.:

$$D_{ij} = \sqrt{(y_j(t) - y_i(t))^2 + (x_j(t) - x_i(t))^2} \leq D_{MW-i} \quad (2)$$

c. The a. i b. conditions must be satisfied by enough other AMPs of the group, so that their total cumulative effect on threat/target, KU_j should be equal or greater than critical threshold of the multiple AMPs cumulative effect, PKU_j, specific to threat/target unit P_j, i.e.:

$$KU_j = \sum_{i=1}^{N} A_{ij} \cdot K_{ij} \cdot U_{ij} \geq PKU_j \quad (3)$$

Where:

- A_{ij} is the assignment coefficient (0/1), which is intended to assignment of the P-j threat/target to AMP-i, in the multitarget swarming models;
- K_{ij} is the main weapon MW-i compatibility coefficient with the P-j threat/target (0/1);
- U_{ij} is the possible effect of the main weapon MW-i on the P-j threat/target.

Three kinds of threat/targets, against which 10, 20 or 30 AMPs, with fulfilled aforementioned conditions, can accomplish successful swarming, have been considered in the model. One sole kind of AMP (tank) has been considered, which has been represented by identical individual possible effect of every AMP (U-i = 0.15), so for the kinds of threat/target considered, values of the critical threshold for successful swarming have been set in the simulator to 1.5, 3 and 4.5.

Two issues of swarming are possible:

a. SUCCESS: AMPs of the group have succeeded to fulfil all necessary conditions and by means of swarming have prevented the threat/target to accomplish its mission (it has not reached the point B, in the example in Fig.5).

b. FAILURE: AMPs of the group have not succeeded to fulfil all necessary conditions, so the threat/target unit has accomplished its mission (it has reached the point B)

The program-simulator has been realized by means of the discrete events system simulation language GPSSWorld [7].

The parameters of the simulated system, consisting of the group of $N = 43$ AMPs, which applies swarming in defending territory during the conflict with $M = 1$ threat/target unit, involve the following:

a) Threat/target parameters:

- Number of threat/target units: $M = 1$
- Initial position of the threat/target unit: A $(x_j(0), y_j(0))$
- Final position of the threat/target unit: B (a, a), a $\in$ {500, 1000,…, 10000 m}
- Law of motion of the threat/target unit T-j: x-axis: uniform motion, $x = X_o + V_{t/t}\cos\alpha t$ y-axis: uniform motion, $y = Y_o + V_{t/t}\sin\alpha t$
- Maximal threat/target unit velocity: $V_{t/t} = 15$ m/s
- Threshold of the critical cumulative effect on the threat/target unit: $PKU_j \in \{1.5, 3.0, 4.5\}$

b) Parameters of the AMPs group:

- Number of AMPs in the group: $N = 43$
- Maximal AMP-i velocity: $V_i = 15$ m/s
- Range of the main weapon MW-i: $D_{MV\text{-}i} = 2500$ m
- Effect of individual AMP-i against the threat/target unit: $U_i = 0{,}15$
- Compatibility coefficient of main weapon MW-i with the threat/target unit: K-i = 1

c) Parameters of the territory of swarming:

- Shape: quadratic
- Dimension: a $\in$ {500, 1000, … , 10000 m}

d) Parameters of the C^4I system:

- Preciseness (prescribed relative distance from the previous known position of every threat/target unit P-j or AMP-j, for which the previous position data are not obsolete): $P_{C^4I\text{-}i} = 150$ m
- Data transfer rate: $V_{RU} = 16$ kb/s.

The primary performance measure of the simulated system consisting of the armed mobile platforms group which, in conflict with the threat/target unit, applies swarming in defending territory is the probability of successful swarming, defined by the expression:

$$p_{ssw} = \frac{N_{ssw}}{N_{ssw} + N_{usw}} \tag{4}$$

where: N_{ssw} is the number of successful, and N_{usw} is the number of unsuccessful swarmings in L conflicts.

V. ANALYSIS OF THE RESULTS

Total of 60 experiments have been executed by means of the realized simulator. In each experiment $L = 10000$ conflicts of 1 target/threat unit and the group of $N = 43$ AMPs, so total of 600000 conflicts have been simulate. The C^4I system preciseness has been set to $P_{C^4I} = 150$ m.

The experimental factor involved:

- Kind of threat/target, expressed through the critical threshold of successful swarming value, $PKU_j \in \{1.5, 3.0, 4.5\}$
- Dimension of the quadratic defended territory, a $\in$ {500, 1000, … , 10000 m}

The results of the experiments have been presented in the figures 6, 7 and 8. For given size of the group of $N = 43$ AMPs, the successful swarming probability has been considered, depending on the defended territory area S [km^2], the front width a [m] and the defended territory occupancy density by the AMPs of the group, G_{AMP} [AMP/km^2], defined by the expression:

$$G_{AMP} = \frac{N}{S} \tag{5}$$

where N is the number of AMPs in the group, and S is the defended territory area in km^2.

The successful swarming probability curves, p_{ssw} [%], as function of the defended territory area, S [km^2], have been presented in Fig. 6.

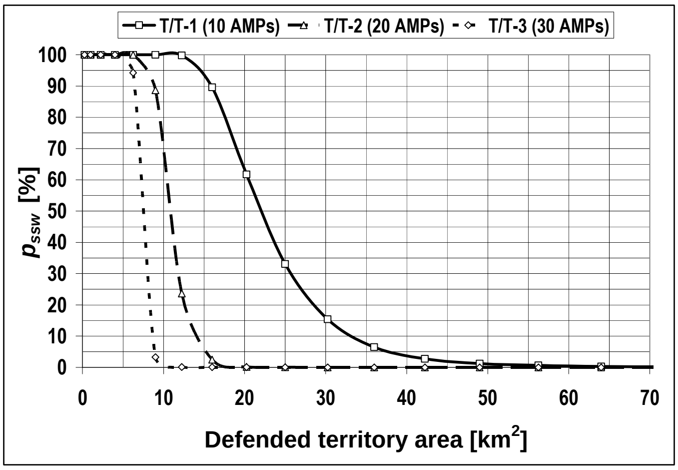

Fig. 6 Successful swarming probability as function of defended territory area

The simulation has been executed for 3 kinds of threat/targets, attacking the territory defended by the group of N = 43 AMPs, applying the swarming tactics: T/T-1, T/T-2 and T/T-3, which need 10, 20 and 30 AMPs necessary for successful swarming, respectively.

The simulated system behaves as expected: the successful swarming probability in smaller defended territories is initially 100%, and after that it decreases as the territory area increases, until becoming negligible. The fastest change is for the T/T-3 threat/target (which needs at least 30 AMPs for successful swarming), slower for T/T-2 (20 AMPs), and the slowest for T/T-1 (10 AMPs). If the probability p_{ssw} greater than 90% is adopted as the criterion for the successful system, one can see that the group of 43 AMPs can satisfy it in the territory which area is about 16 km^2 for the threat/target unit T/T-1, 9 km^2 for T/T-2 and 6.5 km^2 for T/T-3.

One of the usual ways of dealing with the territory defending issues is by considering the defence front width, which has been presented in the Fig. 7.

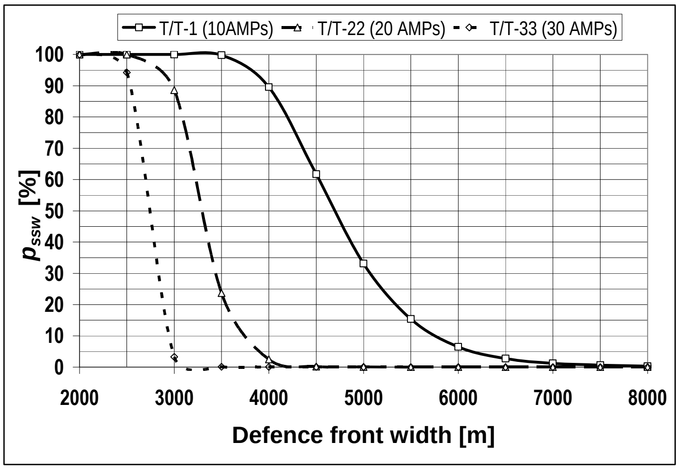

Fig. 7 Successful swarming probability as function of defence front width

The dependency curves are similar in shape to those in Fig.6, with somewhat more moderate change, due to one-dimensional independent variable in the later case, expressed in linear metres. If the same criterion is considered, i.e. that p_{ssw} must be greater than 90%, it can be seen that the group of 43 randomly deployed AMPs can satisfy it at the front width of about 4000 m for the threat/target unit T/T-1, 3000 m for T/T-2 and 2600 m for T/T-3.

Both ways of the results interpreting considered so far require knowledge of the exact number of AMPs in the group (N = 43). Somewhat different way has been presented in Fig. 8, where the swarming success probability has been considered as function of the defended territory occupancy density by AMPs of the group, i.e. of the number of AMPs per km^2. That probability starts from 0% for „empty“ territory, and increases with the occupancy density up to 100%. Such change is the fastest for the threat/target unit T/T-1most, which requires at least 10 AMPs for successful swarming, slower for T/T-2 (20 AMPs), and the slowest for T/T-3 (30 AMPs).

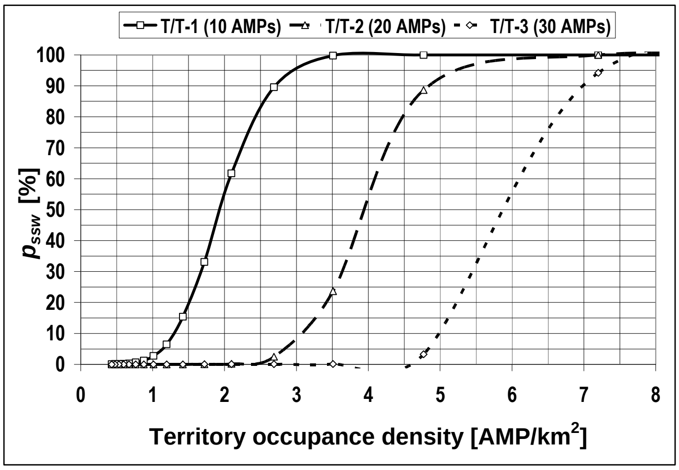

Fig. 8 Successful swarming probability as function of occupancy density

It can be seen the AMP group satisfies the criterion that the p_{ssw} probability should be greater than 90% at the defended territory occupancy density G_{AMP} = 2.7 AMP/km^2 for the threat/target unit T/T-1, G_{AMP} = 4.8 AMP/km^2 for T/T-2 and G_{AMP} = 7 AMP/km^2 for T/T-3.

The results produced by means of the realized armed mobile platforms group swarming simulator could be used for armoured and mechanized units' engagement in territory defence planning.

If the characteristics of the threat/target unit are known, the appropriate density achievement, i.e. number of AMPs per unit of territory area, will result in the value of successful swarming combat action issue.

VI. FURTHER SIMULATOR IMPROVEMENTS

The AMP group swarming simulator realized so far is limited to the case of a single threat/target unit simultaneous occurrence. That limitation is not a problem when relatively smaller AMP groups, which are often engaged in combat action against one serious threat/target, are considered.

However, even an armoured battalion, as the basic tactical unit, has opportunities to apply simultaneous swarming against 2, 3 and even more different threats/targets.

Besides obvious quantitative increasing of the simulator capabilities, this imposes some new issues related to target selection, priorities, AMPs compatibilities with targets and the capabilities of the group for the self-organizing in such situations.

The algorithm will be enhanced in further research, so that the swarming of the AMP group against multiple threats/targets, being simultaneously in the defended territory, could be simulated.

The new algorithm [8], as well as some basic control mechanisms for its implementation [9], have been derived from the basic monotarget/threat swarming algorithm, which has been enhanced by parts for multitarget/threat managing.

The armoured battalion deals with those target/threats on the first come/first served (FCFS) basis, according to their requirements expressed by means of critical cumulative effect treshold of several AMPs participating in the swarming, their priority on the battlefield, and according to battalion's currently available resources, i.e. number of free AMPs which could be engaged against every target/threat.

Certain attention will be paid to different initial deployments of the AMPs of the group. Different initial deployments exploring is one of significant aspect of the research, intended for specific purposes of various situations, when the AMP group has to apply the swarming tactics.

The results obtained in simulation of swarming of the group of AMPs with random initial deployment will be the reference (the worst case), whereas the results obtained for the chosen specific initial deployments should be compared to, for the sake of getting knowledge of advantages that could be achieved by alternative solutions considered.

VII. CONCLUSIONS

The simulation model of swarming of the armed mobile platforms group, defending a territory from the threat/target unit superior to any individual AMP of the group, has been developed and the program-simulator has been implemented by means of the GPSSWorld discrete events system simulation language.

The basic notions of the swarming have been presented, as well as the brief review of the results of the research achieved so far, the simulated system, the simulation model, its algorithmic description, system parameters and performance measure.

A total of 60 experiments have been executed in order to explore the kind of threat/target unit and the defended territory size impacts to success of swarming of the group of armed mobile platforms, initially deployed at random.

Finally, there is a brief regard to limitations of the simulator realized so far and the further research directions.

The transfer to multitarget systems is expected, as well as different initial deployments of the armed mobile platforms group in such situations.

The research is underway at the Union University School of Computing, Belgrade, Serbia. [10].

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