Team 8: Force Protection With ITSim: Base Protection Against Ballistic Weapons

TEAM 8 MEMBERS

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INTRODUCTION

ITSim is a newly developed agent-based simulation environment designed to analyze operations within the broader range of tasks of the Federal Armed Forces, the Bundeswehr.

Modern warfare scenarios are dominated by asymmetric threats with complex non-linear interdependencies and interrelations that traditional techniques of analysis are insufficient to capture. For example, it is often hard to determine whether located humans are opponents (Red) or just civilians (neutral). This distinction can often only be made, when suspicious behavior is observed. Especially, when protecting a base, the response time to suspicious behavior is important to prevent attacks.

The investigated scenario analyses exactly that aspect by using 3D terrain provided by the German Armed Forces.

One of our goals is to investigate the influence of the given terrain. The expectation without terrain is that the red units can be detected as soon as they start to prepare their missile attack. If the terrain data base is used we expect areas in which the opponents cannot be detected, e.g. in a valley. Thus, the existence of opponents can only be determined after they have started the attack by detecting the trajectory. The second goal is to analyze the efficiency of different base defending strategies, which will be defined later on.

SCENARIO

Figure 1 depicts a possible excerpt of the investigated scenario. A blue base is located in 3D terrain. Dark regions mark high terrain elevation whereas bright areas denote lower terrain elevation. Thus, the blue base is located on a hill. It is protected by four guard towers. Two additional towers equipped with cameras are used to observe the surrounding area. They are visualized by tactical icons in the upper part of figure 1. During the course of the scenario, some Red will approach the base in order to attack it with ballistic weapons. Depending on the strategy, a blue unit will try to prevent the attack as shown in figure 1.

The key idea is that the opponents cannot be detected as Red until they start to prepare their attack. Thus, the whole approach time cannot be used to prevent the attack. After the configured preparation time, the opponents launch n missiles and flee afterwards.

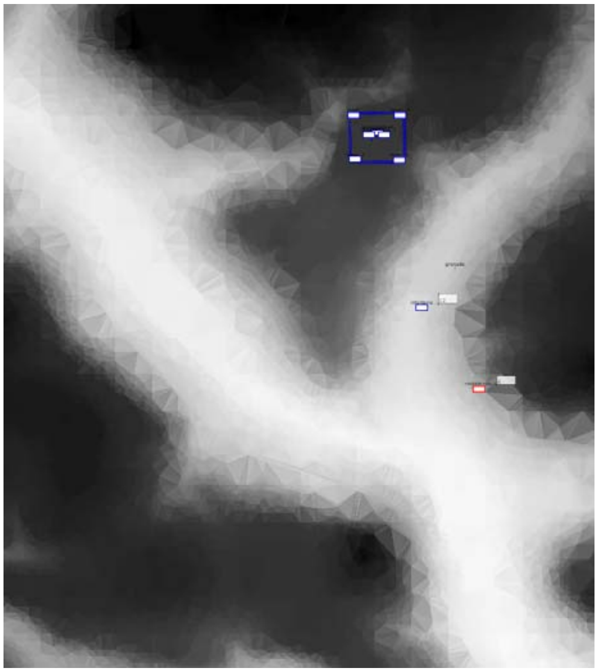

Figure 1: Base in 3D terrain

The scenario's analysis is divided into two phases. The first one is a static classification and the second one is a simulation capturing the dynamics of the strategies.

Static Classification

Before the scenario is simulated dynamically, a static classification is performed. Two important measures are vital for the strategies: ballistic threat and line-of-sight. Areas from which the base can be attacked by ballistic weapons are called *ballistically threatening*. The muzzle velocity of the weapon defines its maximal distance. The terrain defines if there exists an angle that results in a flight trajectory such that the base is hit. The line-of-sight denotes which areas can be observed by the cameras in the base. These cells are called *observable*. Note that both measures strongly depend on the given terrain: if there is none, every point inside a maximal sight range is visible and any point between a given minimal and maximal shoot range is ballistically threatening.

In order to perform the classification, the area around the base is gridded. Afterwards, every cell, i.e. grid element, is checked if it is ballistically threatening and observable. Note that the terrain itself is not gridded but based on precise vector data. According to that classification, three cases exist:

A cell is not ballistically threatening, i.e. the base cannot be attacked from that cell. The Blue don't have to worry about that cell. Therefore, the cell is colored green.

A cell is ballistically threatening and not observable. Thus, the base can be attacked from that cell and there is no line-of-sight to the base. The attackers cannot be identified while they prepare their attack. This is the worst case for the blue forces and the cell is colored red.

A cell is ballistically threatening and observable. Thus, the base can be attacked from that cell and there is a line-of-sight to the Blue. The attackers can be detected while they prepare their attack. The cell is colored yellow.

The result of the classification of the base-case scenario is depicted in figure 2. Each grid cell has an edge length of 11 m resulting in 12,315 cells. 38.9% of the cells are green, 26.8% yellow and 34.3% red. Considering the ballistically threatening cells, only, the majority is not observable. This classification is the base for the simulation.

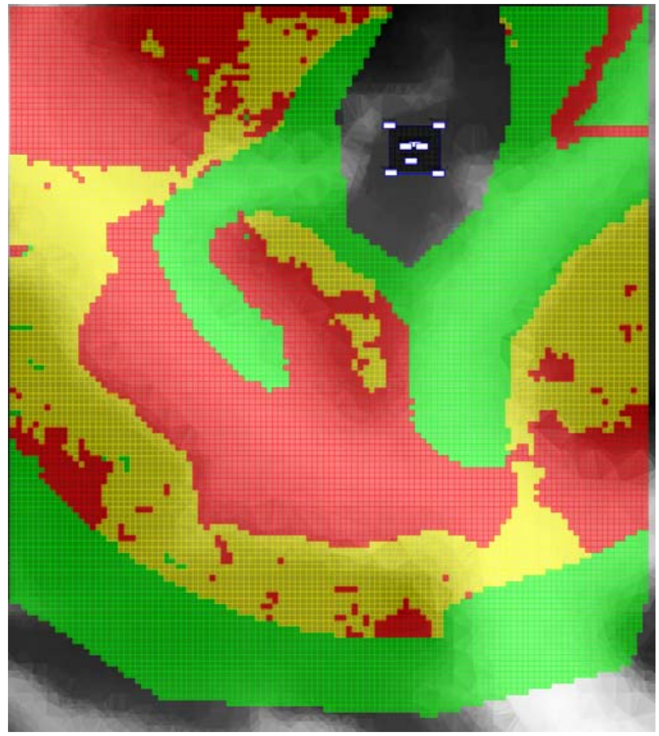

Figure 2: Result of Classification

Simulation of the Strategies

Our second goal is to evaluate different blue strategies against a given red behavior. This kind of analysis may give interesting hints to support the defending of the base. The red strategy is fixed in all experiments. It consists of the following steps:

Generation: the units are generated uniformly distributed outside the base. Their affiliation is neutral, i.e. they cannot be detected as hostile.

Approach: a yellow or red cell (i.e. a ballistic attack is possible from that cell) is selected and moved to. The unit is still not detectable as hostile.

Preparation: two cases exist. If the attacker can detect any blue unit it gets discouraged and flees. Otherwise it starts to prepare its attack. From that point in time, it can be detected as hostile by the Blue. As soon as a blue force is detected by the red unit, it aborts its preparation and starts to flee. Thereby note that the cameras' sight range is much higher than the one for regular ground troops including red attackers and blue defenders. For our experiments, we assume a preparing time of five minutes.

Attack: the Red starts to fire a previously defined number of projectiles at the base. From this point in time, the attacker is detected as hostile by the blue defenders if it has not already been. Between the shots, the attacker has to re-load. Afterwards, it flees.

The two Measures of Effectiveness (MoE) of this scenario are: The primary one is the number of prevented shots at the base. This happens if the attacker is neutralized or discouraged before the attack is started. The secondary MoE is the number of neutralized attackers.

Currently, the Blue have three different strategy options to prevent ballistic bombardment at their base:

Pursue from Base (PfB): a blue *Quick Reaction Force (QRF)* is located inside the base and pursues as well as attacks the Red as soon as they have been detected. The attacker can be observed by the cameras or they reveal themselves by shooting projectiles at the base.

Camouflaged Emplacements (CE): camouflaged spotters are located outside the base. They can detect the Red but not vice versa. As soon as the red units are located, their position is reported to the base and the *QRF* starts the counterattack at the Red.

Show of Forces (SoF): patrols move around the base. They can detect the Red and can also be detected by these. If any red force is located, the nearest patrol starts a counter attack. Note that there is no *QRF* in the base as in the other strategies. If the Red detect any approaching patrol, they flee.

Figure 3 shows the classification of the strategy *CE*, where two emplacements are located in the valley. The circles denote their maximal sight range. Many cells inside these circles turned yellow since they became observable. The green cells remain unchanged since the ballistic threat depends on the terrain, only. 34.2% of the cells are yellow and 26.9% red. This is an improvement of about eight percent. The majority of the ballistically threatening cells are observable by the Blue.

The initial situation of strategy *SoF* is as follows: two patrols are located in the valley. The first one patrols between two waypoints northward of the base. The second one patrols southward. The *QRF* is no longer inside the base, because the patrols can pursue and attack the Red directly.

Note that the camera towers inside the base always support the detection of the Red. As mentioned above, the red units can only be detected after they have started preparing their attack. The *QRF* has limited time to reach the attackers before they can fire their rockets.

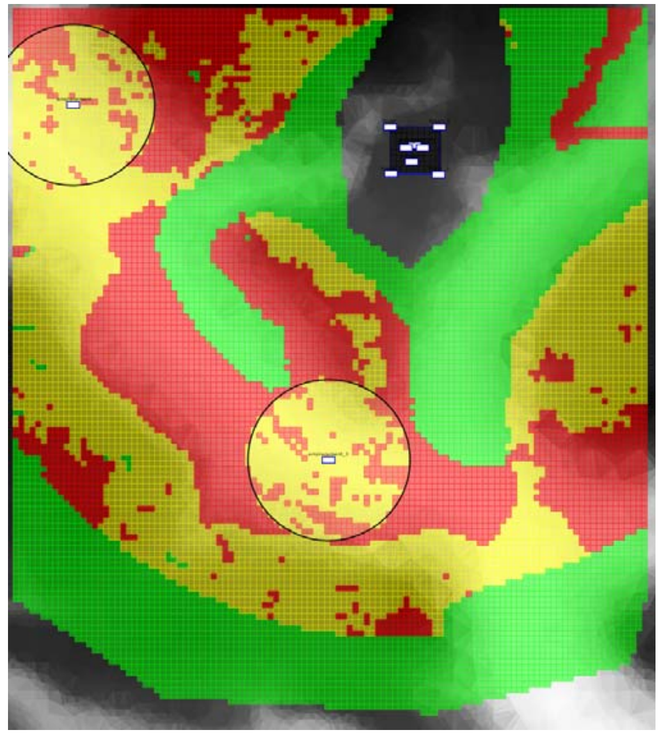

Figure 3: Classification of *CE*

We expect the following results having strategy *PfB* as basis for our comparison:

CE: when the emplacements are positioned such that a large area becomes visible that has not been before (e.g. many cells turn from red to yellow), more attacks can be prevented since the *QRF* can act earlier. Thus, we expect more success for the Blue.

SoF: if the patrol points are selected wisely, the patrols can also cover many of the invisible cells and attack the Red earlier. Another advantage is that the distance from the patrol to the red attackers might be shorter than the one from the base to the Red. A third positive effect for Blue is that the Red might have to flee more often since they can detect the patrols by themselves and get discouraged. Thus, we expect this strategy to be the best.

The influence of omitting the terrain (i.e. the whole area being flat) on the three strategies is expected as follows:

PfB: the success rate will rise since the red units can always be detected as soon as they start to prepare their attack. Thus, the *QRF* always has the maximum time for its reaction. Note that this does not necessarily mean that the attack can always be prevented.

CE: this strategy will not improve the MoE of *PfB* since it only enlarges the visible area that is already maximal anyway (the cameras' sight range is larger than the range of the red ballistic weapons). Thus, we expect similar results as for *PfB*.

SoF: the advantage of the enlarged visible area drops since the whole area is visible. But the advantage of discouraging the Red stays. Additionally, the approach distance to the attacking enemies might be shorter since the patrols are outside the base. Thus, we expect this to be the best also if the terrain is omitted.

We present the analysis of our results in the following section.

RESULTS AND ANALYSIS

As already mentioned in the introduction, we want to investigate two main questions during the evaluation of this scenario:

What is the influence of the terrain?

How effective are the different strategy options of the blue base defenders?

To answer these questions, we have determined a primary and a secondary MoE. The former one is the percentage of prevented attacks and the latter one is the number of neutralized attackers.

We have performed more than 170,000 simulation runs with different parameter variations. The variation covers the terrain, the velocities of the Red and Blue, as well as the different strategies.

Influence of the Terrain

In order to determine the terrain's influence on our MoE, we have evaluated the strategy *PfB* with blue velocities b1, b2 and b3 km/h as well as red velocities of r1, r2, r3 km/h, respectively. All nine experiments were performed with and without terrain resulting in 18 experiments.

Table 1 contains the results of the strategy *Pursue from Base*. We can easily confirm that both MoEs *prevented shots* and *prevented all shots* do not depend on the velocity of the Red since the variation caused by the red velocity is less than one percent given the blue speed.

Blue Speed	Red Speed	Prevented Shots	Prevented All Shots	Neutralized Attackers
b1 km/h	r1 km/h	21.02 %	18.14 %	57.79 %
b1 km/h	r2 km/h	20.96 %	18.14 %	40.07 %
b1 km/h	r3 km/h	21.02 %	18.14 %	36.89 %
b2 km/h	r1 km/h	26.17 %	21.06 %	75.37 %
b2 km/h	r2 km/h	26.16 %	21.05 %	53.05 %
b2 km/h	r3 km/h	26.09 %	20.96 %	46.09 %
b3 km/h	r1 km/h	31.10 %	25.32 %	86.21 %
b3 km/h	r2 km/h	31.10 %	25.32 %	65.50 %
b3 km/h	r3 km/h	31.10 %	25.32 %	51.82 %

Table 1: *PfB* with terrain

This can be explained by considering that a shot can only be prevented if the *Quick Reaction Force* arrives at the attacking unit while it is preparing its attack or if the Red recognizes a blue unit during its preparing phase. Clearly, the former event only depends on the blue velocity while the latter one does not depend on any velocity. However, the red velocity is important for our secondary MoE, since the number of neutralized attackers significantly rises when the Red get slower or the blue defenders become faster. The reason is simply the fact that more attackers are able to escape when they are faster.

Note the difference between *prevented shots* and *prevented all shots*: the former one denotes the number of prevented shots, whereas the latter one denotes if the base attack has been prevented completely throughout one simulation, i.e. if the red attacker has been discouraged or neutralized while it was preparing its attack. Thus, the latter one is a more strict measure. This explains why its percentage is less then *prevented shots* in all variations and strategies.

Blue Speed	Prevented Shots	Prevented All Shots	Neutralized Attackers
b1 km/h	48.15 %	46.85 %	84.58 %
b2 km/h	64.84 %	61.83 %	93.78 %
b3 km/h	78.76 %	74.67 %	98.29 %

Table 2: *PfB* without terrain

Table 2 contains the results of strategy *PfB* without terrain. Since the red attacker can be seen as soon as it starts to prepare its attack, the blues success is significantly superior. Note that this does not result from a better strategy itself but it is just the lack of realism that raises Blue's success. The average gain factor of *prevented shots* and *prevented all shots* is about 2.5. The number of neutralized attackers is also higher in all cases than without terrain as can be seen in table 1. We compared the influence of the terrain only with respect to the strategy *PfB*. This is sufficient since it is clear that the terrain has an influence. We can quantify this influence with respect to our two MoEs.

However, the terrain's influence can also be seen by the static classification discussed above. If there is no terrain, there exists no red cell, i.e. no cell is ballistically threatening and not observable at the same time. The number of green cells decreases from 3,299 to 2,273 since all cells can be attacked within the given minimal and maximal range of the ballistic weapons (defined by its muzzle speed). All remaining 10,042 cells are yellow compared to 4,215 yellow cells if terrain is given. Thus, the static classification also supports the claim that there is a significant influence of the terrain.

Of course, this quantification is limited to this scenario with this strategy. But in the real world there is terrain and we cannot simply omit it in data-farming since this distorts the analysis significantly. The results of the strategy comparison are presented next.

Comparison of the Strategy Options

We run the scenario with all three different strategies. Each run was performed with terrain and the same velocity settings for the units as above: b1, b2 and b3 km/h for blue defenders and r1, r2 and r3 km/h for red attackers. Table 1 from above provides the results for the strategy *PfB*, which serves as base-case. We compare the other strategies with respect to *PfB*.

Blue Speed	Prevented Shots	Prevented All Shots	Neutralized Attackers
b1 km/h	23.24 %	19.00 %	54.06 %
b2 km/h	31.19 %	23.75 %	69.04 %
b3 km/h	37.89 %	29.32 %	76.26 %

Table 3: Results of strategy *CE*

Table 3 shows the results of the second strategy *Camouflaged Emplacements*. Similarly to *PfB*, the red velocity is not important for the MoEs *prevented shots* and *prevented all shots*. Due to the earlier detection in the areas that are covered by the spotters (see figure 3), the blue *QRF* can start earlier. Since the number of yellow cells rises from 26.8% to 34.2% because of the additional spotter (see figures 2 and 3), one might expect that the primary MoE also rises by eight percent. This is not true. The MoE rises with respect to the blue velocity. If blue moves with b1 km/h, the MoEs *prevented shots* and *prevented all shots* rise by 2 and 0.8 percent, respectively. When the blue speed is b2 km/h the MoEs rise by 5 and 2.5 percent, respectively. The largest gain occurs if the blue speed is b3 km/h: 6 and 4 percent, respectively. The reason therefore is the distance between the base and the additional observable cells (see figure 3). The distance is so large that the *QRF* cannot prevent all attacks although it starts earlier. The faster the *QRF* moves, the more attacks can be prevented.

The gain of strategy *CE* with respect to the MoE *neutralized attackers* compared to *PfB* is linear. Roughly 9 percent more attackers are neutralized than with strategy *PfB*.

Blue Speed	Red Speed	Prevented Shots	Prevented All Shots	Neutralized Attackers
b1 km/h	r1 km/h	67.35 %	64.95 %	68.31 %
b1 km/h	r2 km/h	69.22 %	66.18 %	64.01 %
b1 km/h	r3 km/h	71.63 %	68.74 %	58.55 %
b2 km/h	r1 km/h	73.88 %	70.81 %	67.27 %
b2 km/h	r2 km/h	72.91 %	70.27 %	68.05 %
b2 km/h	r3 km/h	74.84 %	72.19 %	65.28 %
b3 km/h	r1 km/h	82.11 %	78.97 %	62.55 %
b3 km/h	r2 km/h	78.17 %	74.88 %	69.38 %
b3 km/h	r3 km/h	78.35 %	75.04 %	68.47 %

Table 4: Results of strategy *SoF*

The results of the last investigated strategy *Show of Forces* can be seen in table 4. First of all, we notice that the red velocity has influence on the MoEs *prevented shots* and *prevented all shots*. However, the blue velocity dominates the red one, i.e. the higher the blue velocity is, the superior are the MoEs. The faster the Blue move, the larger is the area they can observe in a certain time frame. Additionally, they can reach an observed red attacker in shorter time. If the blue speed is constant, the red velocity has an influence on the MoEs, but there is no unambiguous trend. The reason therefore is the timing of the parallel movements of the red attackers and the blue patrols. For example, if the velocities are set such that a blue patrol prevents an attack by discouragement, a faster as well as a slower red attacker might not be discouraged or might be detected later or earlier.

Another interesting result is the reason for the high percentages of prevented attacks. The number of attackers that got discouraged before they started the preparing of their attack is much higher in this strategy as can be seen in table 5.

Strategy	Prevention by Discouragement
PfB	1.38 %
CE	1.29 %
SoF	69.20 %

Table 5: Percentage of *Prevention by Discouragement*

Prevention of Discouragement denotes the percentage of the discouraged red attackers, i.e. the ones that detect a blue immediately before starting their preparation, with respect to all attack preventions. This rate is low and similar for the strategies *PfB* and *CE*. But it rises dramatically in strategy *SoF*. Thus, the main reason for its success is that the Red can detect the blue patrol and flee before they attack. Transferring this result to reality might become difficult since no one can count this number. Thus, in reality this strategy might be underestimated, because the correct MoE cannot be determined in the real world.

Summary of the Results

Figure 5 depicts a summary of the MoE *prevented all shots* with all strategies. Comparing PfB with terrain, CE and PfB without terrain, we can see that the blue velocity is more important if more cells can be observed. The following statements can be derived by our analysis:

- Terrain information has a huge impact on the investigated MoEs. This statement is supported by the static classification as well as the simulation of the strategy *PfB*. Thereby note that the strategy *PfB* without terrain has a higher MoE than *PfB* with terrain and *CE*. Only *SoF* is superior. The main reason is the high rate of discouraged enemies.
- *Camouflaged Emplacements* help to raise the success of the blue defenders in comparison to *PfB* due to an enlargement of the observable area. The Blue have to assure that these additional yellow cells can be reached in time by the *QRF* in order to realize the potential advantage. The impact of emplacements is supported by the classification and simulation.
- *Show of Forces* is the best strategy option. It outperforms all other strategies, even *PfB* without terrain. The main reason is the fact that it is able to discourage the attackers before they start their preparing.

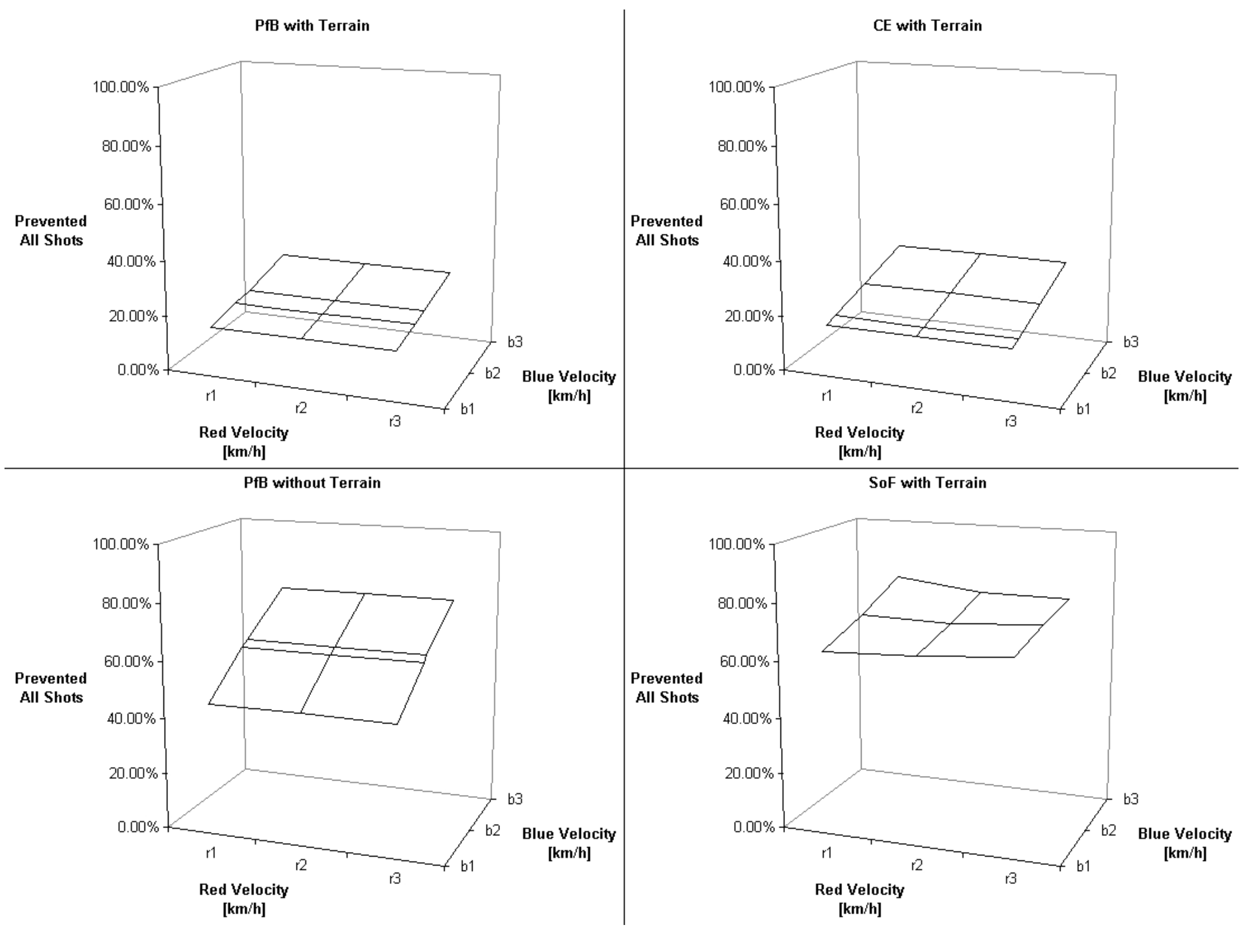

Figure 5: Summary of Results

Given these results some common hints for the defenders can be derived. Due to the success of *SoF* it might be useful to substitute camouflaged emplacements by visible emplacements that can also discourage the enemy. It is important to note that the number of discouraged attackers cannot be determined in reality. Another option is to raise the speed of the *QRF*, e.g. by using helicopters instead of ground troops.

Limitations of the Strategy Comparison

The performed strategy comparison is just a starting point. Basically, one instance of each strategy has been evaluated. This is useful if several existing strategies have to be compared with each other.

With the help of the static classification, we would like to answer the following questions in future:

How many emplacements are needed to cover all cells?

How can *n* emplacements be distributed such that most cells are covered?

What is a good ratio between covered cells and used emplacements?

The first question is academic since there will not be enough resources available in practice. But it gives an upper bound for the resource planning. The answer to the second question requires an optimization of the application of available resources. The third question is very interesting if there is a base protection to be planned. We expect a double bend curve if we map the emplaced units to the covered cells. Then, there would be a point from which any additional emplacement merely raises the number of observed cells.

Analogously, the answer to the following questions could be given using the strategy simulation:

How many emplacements/ patrols are needed to avoid any attack?

How can *n* emplacements/ patrols be placed such that most attacks are avoided?

What is a good ratio between avoided attacks and used emplacements/ patrols?

These questions are very similar to the ones above. But note that their answering is much more complex since the dynamics (especially the movement of the Red) have to be captured. Additionally, a patrol cannot simply be placed at a certain coordinate but its waypoints related to the arrival times are also important.

In order to answer these questions at least semi-automated, we have to extend our current approach with optimization techniques which are able to derive strategy settings automatically. Such a system could use evolutionary algorithm combined with data-farming similar to Automated Red Teaming (ART) and Automated Co-Evolution (ACE).

Another limitation of the performed analysis is the restricted variation of the parameters. We just changed the velocity of the units and the position of the attackers. Additional parameters can be varied in order to confirm the analysis. These parameters are sight range for the camera towers and standard units, number of attackers and defenders, initial position and waypoints of the blue patrols, range of the weapons of Red and Blue, duration of the attack preparation of the red attackers, reload time of defenders and attackers, number of shots of the Red before their fallback, etc. Considering all these parameters, the number of required experiments grows exponentially.

CONCLUSIONS

The presented analysis is a first approach of incorporating terrain information into our agent-based simulation system ITSim. It enables the analysis of many interesting and promising scenarios that might give some decision-support to leaders of the German Armed Forces. Especially the possibility to evaluate different strategies under real-world constraints is an enormous step into that direction.

As expected, the terrain information complicates the base defending task for the blue forces. But it is vital to consider all parameters that influence the MoE of given scenarios significantly. A realistic model of scenarios is important for the transfer of gained knowledge to the real application.

From an analytic point of view, military operations are highly non-linear processes in which a wide variety of factors can have an impact on what is going to happen. Even small-scale decisions can have serious effects and cause an operation to take very different courses. The key to success is the appropriate modeling of the planned operation. To achieve this, the model must be scaled such as to generate sufficiently general statements that are valid for a wide range of operations. Thus, a satisfactory analysis of the blue strategies is future work since several parameters of each strategy (e.g. number of units, position of units/ waypoints etc.) have not been investigated yet. We only have analyzed one representative of the strategies *CE* and *SoF*, respectively, since only one number of units and one patrol way have been investigated. Note that *PfB* can be considered as sub-strategy of *SoF*, because there is only one patrol that is placed inside the base. The reason for this insufficient analysis is the required computing power. Over 170,000 simulation runs have been performed after the workshop in order to generate the presented results. During the workshop, we were able to perform several hundred runs per design point, only. We calculated two design points for the strategy *CE* and omitted *SoF* completely.

Additionally, other strategy options for the blue forces can be imagined, e.g. a mixture of the strategies *CE* and *SoF*. The red strategy can also be changed although we consider it as very plausible and realistic. A change of a unit's behavior is quite simple to manage since ITSim is designed to provide the best possible support to the modeler and therefore has a completely agent-based structure. All the entities of the simulation (terrain, units, technical elements, weather, communication, etc.) are simulated by autonomous agents. This technology provides the possibility to adapt the system to the requirements of the given operation model in spatial (cancellation of the operation area, aggregation of units), temporal (time model) and functional terms (behavior of units, technical and environmental elements). The scaling of the model can be adjusted to the simulation runtime so that uninteresting phases can be simulated in time lapse mode or low resolution. Additionally, all behaviors of the agents are built following a service-oriented approach. Thus, the existing services can be reused when developing new strategies.

Another future work might be the development of a system similar to Automated Red Teaming (in this case Blue Teaming) and Automatic Co-Evolution (ACE) aiming in automatic evaluation and comparison of the different strategies. One core requirement for such a system is the integration of experiment design, cluster control and result analysis. Additionally, the strategies (technically: parameter variations) must be guided heuristically in order to avoid a possibly infinite search.