Team 10: Robustness Analysis with ITSim: Patrol Planning and Plan Execution Simulation

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INTRODUCTION

ITSim is a general purpose simulation system for decision-support. It focuses on the simulation of coherent processes and provides additional methods for examining optimization tasks within the broader range of tasks of the German 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 hard to determine the cost and benefit of force deployment at several bases in the *area of operation (AOO)*. On the one hand, the deployment at several bases has a positive effect since the forces are spatially closer to the points where mission objectives have to be accomplished. On the other hand, longer supply chains have to be guarded. IT-AmtBw and Fraunhofer IAIS are currently developing an extension to ITSim that provides decision support on this optimization problem. Several factors are involved in such an investigation. One core factor is the generation of a patrol plan, which is a schedule for all designated forces for a certain time horizon. It maximizes the presence at certain *points of interest (POI)*. A POI is an element of a mission that requires special actions, like reconnaissance, presence, show of forces or CIMIC activities. It is formalized as a *location*, desired visit *frequency*, a certain *duration* and a *weight*. Thus, a POI located at *location* is to be visited regularly with a time interval of *frequency*. Each visit lasts *duration* time units. The relative importance of one POI with respect to the other ones can be modeled by assigning *weight* as a multiplier.

The overall questions to be answered with an investigation like this are the following:

- Is it better to distribute own forces to several bases, or instead to concentrate them in one single base ?
- If the forces are to be distributed, which distribution is optimal ?

Note that we cannot answer these questions at this early stage of development. Additionally, many factors are important for a well-founded estimation. At this workshop, we wanted to answer the following questions:

- Can ITSim find optimal patrol plans with respect to the patrol presence at given POIs ?
- Is the given (technical) concept of patrol presence also suitable for military definitions of patrol presence?
- What is the influence of weighted, i.e. prioritized, POIs?
- How robust are the generated patrol plans against execution flaws?

The following two sections introduce the scenario at hand as well as the performed analyses and their results. The investigation is divided into two phases, optimization and simulation. Both parts are discussed in the sections. The final section gives a conclusion and suggestions for future work.

Figure 1: Scenario Overview

SCENARIO

Figure 1 depicts the investigated scenario, which is located in Germany. The area has a size of roughly *35* km times *29* km. Three bases, marked with a red circle, are located in the scenario. The other icons represent POIs, which have to be included in the patrol plan with a certain time of patrol presence.

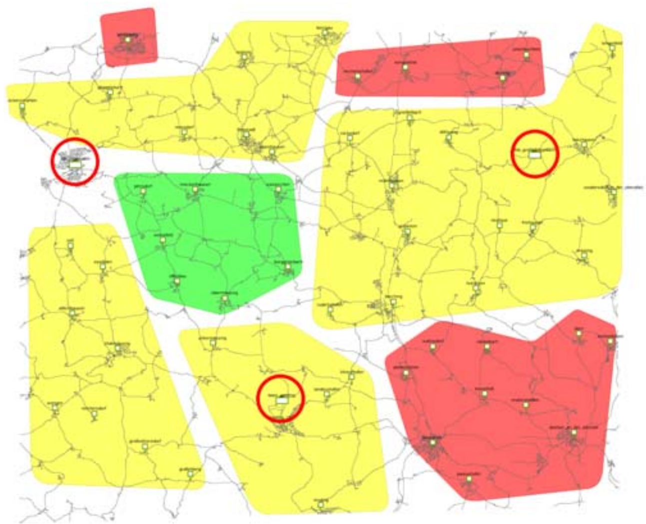

Figure 2: Roads and classification of POIs

Figure 2 depicts another view at the scenario. The roads (dark lines) are imported from a data source of the German Armed Forces. The POIs are categorized into several classes: red, yellow and green. To each class different parameter values are assigned. The analysis of the scenario is divided into two phases, an optimization and a simulation phase, both discussed in the following.

Optimization Phase

During this phase, an optimal schedule (patrol plan) for all patrols is generated. This is a hard optimization problem. The patrols are constrained by their fuel capacities as well as by a maximal operational duration per day, which must not be exceeded. In our experiments, the patrol plan has a time horizon of *20* days, i.e. each patrol is assigned tasks for *20* days. Every patrol must return to its home-base every evening in order to rest and re-supply. All patrols have the same average speed of *40* km/h. In Table 1, the parameters of the different classes of the POIs are listed.

Class	Frequency	Duration
Red	12 h	1 h
Yellow	24 h	2 h
Green	36 h	3 h

Table 1: Parameters of the different POI classes

After the patrol plan has been generated, it can be integrated into the scenario and its execution can be simulated.

Simulation Phase

During the simulation phase, the robustness of the generated plan is analyzed. This is important since there are always discrepancies between operation planning and operation execution. Thus, the best plan during optimization might not be the best plan during execution.

In order to disturb the plan execution, we have defined some unexpected events that occur stochastically: *Blocked roads* and *stochastic patrol durations*. In order to enforce re-routing of patrols, some roads are blocked stochastically. Thus, the patrols cannot take the shortest route and the required time to reach a POI or a base increases. The second event reflects the effect that mission execution at a certain POI is not always straight-forward as expected. Delays as well as unexpected fast accomplishment can occur. Thus, the POI duration is not deterministic but stochastic.

The *Design of Experiment (DoE)* as well as the results are introduced in the next section.

RESULTS AND ANALYSIS

In this section, we introduce the conducted experiments and present the analysis which is used to answer our questions stated in the introduction. The results are presented according to the two phases mentioned above.

Figure 3: Patrol-centric view on a patrol plan

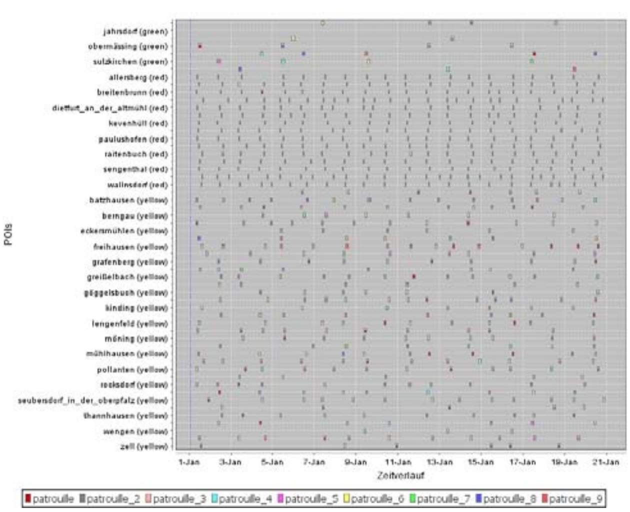

Figure 4: POI-centric view on a patrol plan

The first two questions were discussed very detailed at the workshop. We implemented many views on the resulting plans, e.g. Figure 3 and Figure 4, in order to analyse the quality of each generated plan. The former figure shows the actions of the patrols in time (green: at base, red: move, blue: patrol, yellow: sleep). The latter shows the visits of the different patrols at each POI over time.

Our discussions revealed that the technical concept of patrol presence is *not* sufficient for a military decision maker. The reason for that is that there are many, often conflicting, goals to be pursued. We will extend ITSim in future upgrades to overcome this shortcoming by introducing more optimization criteria and performing a multi-dimensional optimization. One additional but not sufficient criterion is introduced in the following and will be compared with the current technical criterion.

Optimization Results

The results of the optimization are discussed below. We first generated a patrol plan according to the scenario depicted in the figures above. Seven patrols are distributed over the three bases. The influence of different weights for the POI classes should be determined. Therefore, we calculated the number of POIs which have been satisfied, i.e. where the desired patrol frequency is never violated. When the POI is visited at a certain point t in time, the next visit should happen exactly at point t', which is t plus the duration of the visit and the desired frequency time. When the next visit happens at t' plus minus a certain tolerance value, the next visit is in time. The tolerance value is a percentage of the frequency of that particular POI. A POI is satisfied if all visits are in time.

Three different weight combinations for the three POI classes (red, yellow and green) have been selected. We call them single, double and triple weighting. In the first case, all classes have the same weight, in the second case red is twice as important as yellow which is again twice as important as green. In the last case, the weights differ by the factor three.

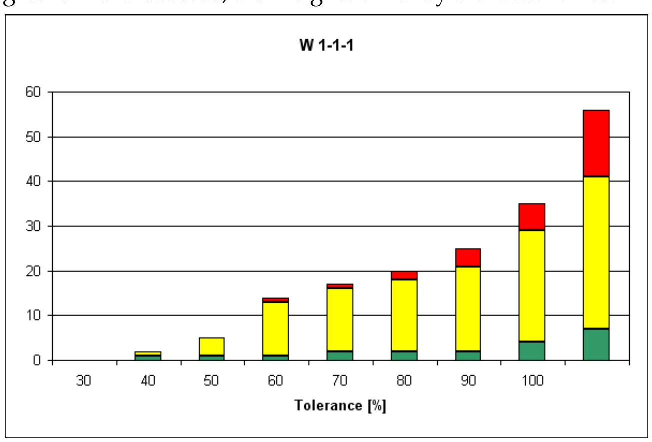

Figure 5: Satisfied POIs with 'single weighting'

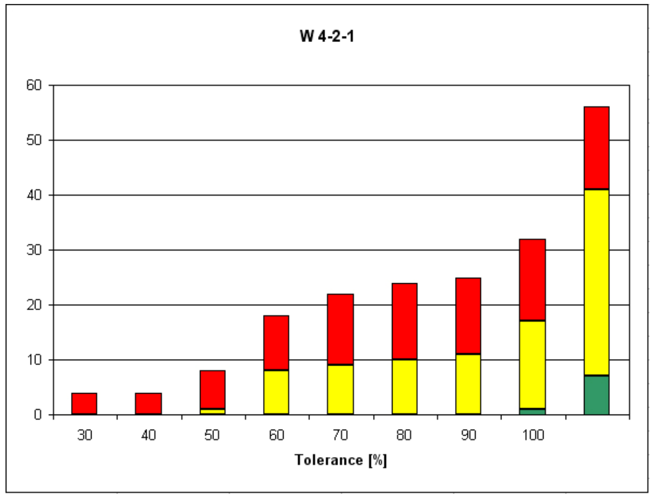

Figure 6: Satisfied POIs with 'double weighting'

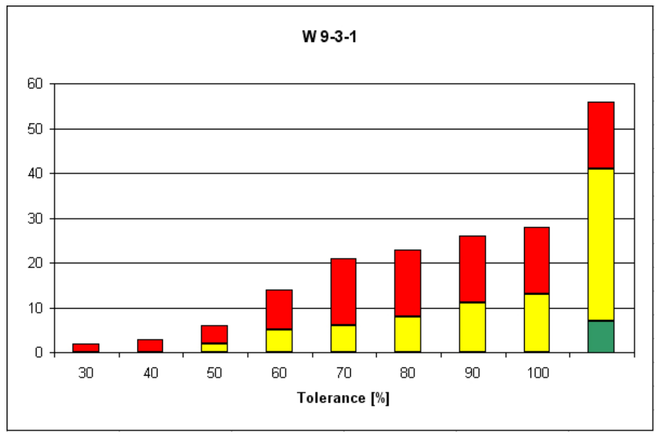

Figure 7: Satisfied POIs with 'triple weighting'

Figure 5 to Figure 7 depict the results of the experiments. The last bar always represents the overall number of red, yellow and green POIs, respectively. The higher the difference in weight, the more red POIs are satisfied. At the same time, the number of overall satisfied POIs decreases since the patrols are concentrated on the important POIs and do not take much care about the unimportant ones. Thus, the user has to carefully select its prioritization.

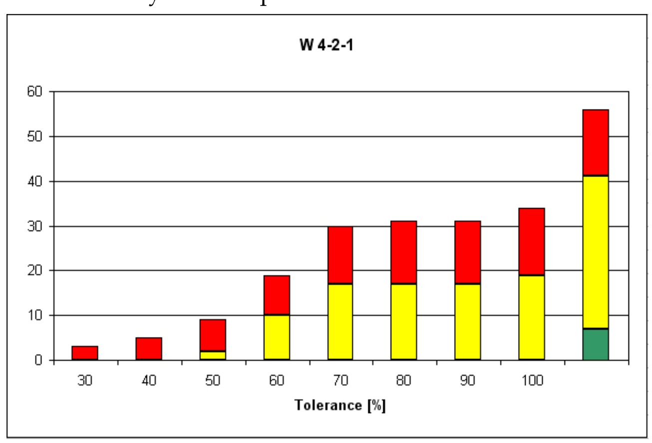

Figure 8: Satisfied POIs with 'double weighting' with one base

The aim of the next experiment is to compare the deployment to three bases with a deployment to one base, namely 'fob_großalfalterbach', the top-right base depicted in Figure 1. Since only one base has to be defended, two more patrols, namely nine, can be employed for patrolling. We performed one experiment with 'double weighting'. The results for one base are depicted in Figure 8 and can be compared with Figure 6, where three bases were used.

Tolerance	Green		Yellow		Red	
	1	3	1	3	1	3
30%	0	0	0	0	3	4
40%	0	0	0	0	5	4
50%	0	0	2	1	7	7
60%	0	0	10	8	9	10
70%	0	0	17	9	13	13
80%	0	0	17	10	14	14
90%	0	0	17	11	14	14
100%	0	1	19	16	15	15

Table 2: Number of satisfied POIs with 'double weighting' for one and for three bases

Table 2 shows the number of satisfied POIs clustered into their class with respect to a given tolerance. The numbers are calculated for the deployment to one and three bases. We can see that the deployment is superior if only one base is used. The green class with *100%* tolerance is the only outlier. This is also confirmed by our technical optimization criterion, the patrol presence. The patrol plan with seven patrols and three bases gained a value of *1613*, wheras the patrol plan with nine patrols in one base realized a value of *1654*. Nevertheless, it seems reasonable to use a multi-dimensional optimization method in future.

Simulation Results

For the simulation of the patrol plan execution, we used the best plan of the double weighting setting with one base. As mentioned above, the unexpected events were road blocks and stochastic patrol durations at the POIs. Additionally, we varied the speed of the patrols.

Factor	Min	Max	Unit
Patrol Speed	20	60	km/h
Blocked Roads	0	500	
Block Duration	1	48	Hour
Block Start	0	19	Day
POI Duration	20	180	Minute

Table 3: NOLH design

Table 3 contains the *Nearly Orthogonal Latin Hypercube (NOLH)* [1] design of our experiment. Every parameter configuration has been run with *17* different seeds. The simulation part revealed that our plans are very robust since no varied parameter has a statistically significant impact on the regarded *Measure of Effectiveness (MoE)*, which is the number of satisfied red, yellow and green POIs. The main reason therefore is probably that all delays are compensated by the nightly rest. Additionally, the number of closed roads was probably too small. We have to invest more time in order to evaluate the robustness of the generated plans in more detail.

CONCLUSION

Intelligent force deployment is a difficult optimization problem. Many, sometimes conflicting, critera influence the final decision. The patrol plan generation module of ITSim, which is currently still under development, might support a human decision maker, i.e. the commanding officer.

In our goal to analyse the robustness of the patrol plans we foccussed at first on the plan generation itself and discussed appropriate quality measures for plans. A broadly accepted notion of an optimal patrol plan is very hard to develope since it is always subject to the current situation and main intent of the decision maker. One way out of this dilemma is to integrate many different possible critera and optimize them simultaneously in a multi dimensional optimization (e.g. [2,3]). Afterwards, the decision maker can select among the solutions and adjust the tradeoffs manually.

Another very important idea for future work is the investigation of the tuning of technical parameters of the optimization in ITSim. Since a genetic algorithm is employed, many parameters are used to adjust the search heuristic, i.e. the genetic operators. Perhaps a more optimal parameter configuration can be found automatically.

REFERENCES

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