Aalto University
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Adversarial risk analysis for simulation-based assessment of weapon portfolios

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Nordic Military OA Conference 2017, Stockholm, September 6-7, 2017

Systems Analysis Laboratory

Agenda

1. Adversarial Risk Analysis (ARA)
2. Assessing Portfolio Efficiency
3. Case Example

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1. **Adversarial Risk Analysis (ARA)**
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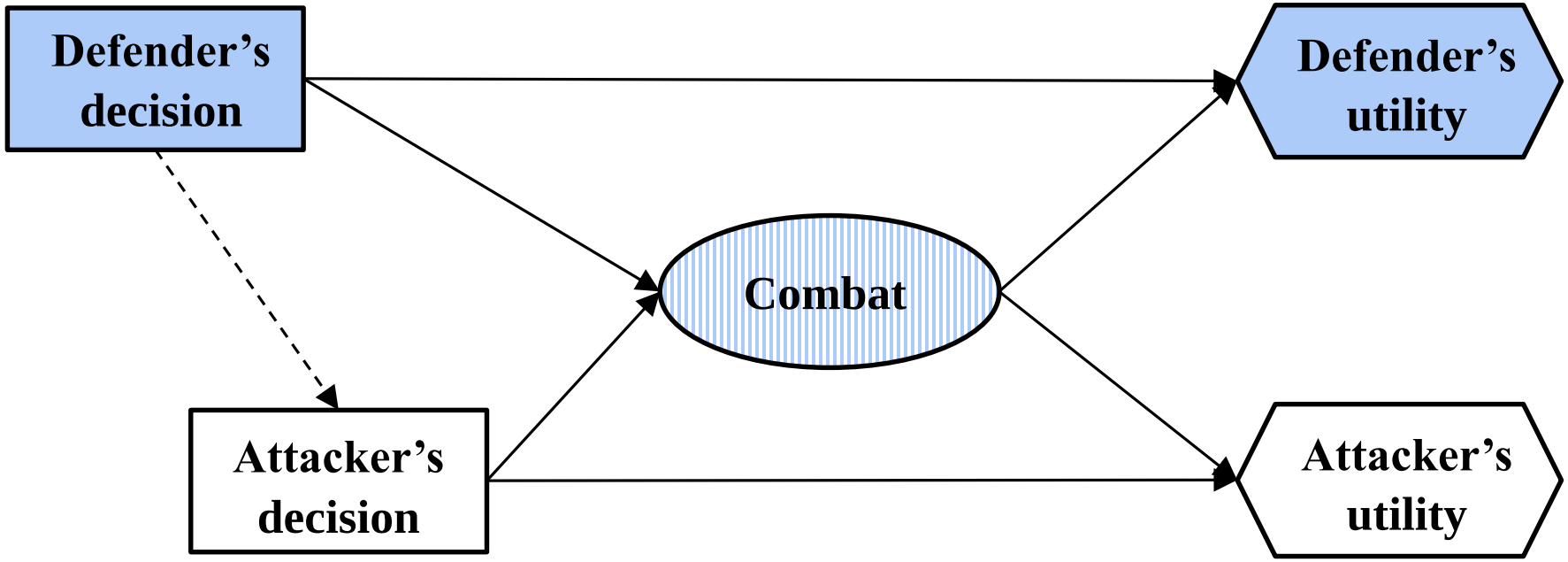
Adversarial Risk Analysis (ARA)

- Combines statistical risk analysis with game theory.
- Helps analyze problems in which intelligent actors with conflicting interests make interdependent decisions under uncertain outcomes.
- Has been used in counter-terrorism and corporate finance, for example.

Relevance to Military OR

- Military problems resemble those of counter-terrorism .
- ARA can be used to inform resource allocation or reconnaissance decisions, for example.
- ARA complements earlier methods and tools.

An Influence Diagram



Solving ARA Problem for the Defender

- Find the Defender's best decision assuming that Attacker maximizes his expected utility.

- Which decision $d \in D$ maximizes Defender's expected utility

$$\psi_D(a, d) = \int u_D(c)\pi_D(c|a, d)\, dc$$

when Attacker chooses action $a \in A$?

A Possible Step by Step Breakdown

1. Estimate the utility function u_D of Defender.
2. Express the uncertainty about Attacker's utility function u_A and his estimate about probabilities of consequences π_A by putting a probability distribution F over (u_A, π_A).
3. Solve the problem from the perspective of Attacker to estimate the probability of his decisions
$$p_D(a|d) = \mathbb{P}_F[a = \text{argmax}_{x \in A} \psi_A(x, d)],$$
where
$$\psi_A(a, d) = \int u_A(c) \pi_A(c|a, d)\, dc$$
4. Solve the expected utility maximizing decision
$$d^* = \text{argmax}_{d \in D} \int\ p_D(a|d) \psi_D(a, d)\ \ da.$$

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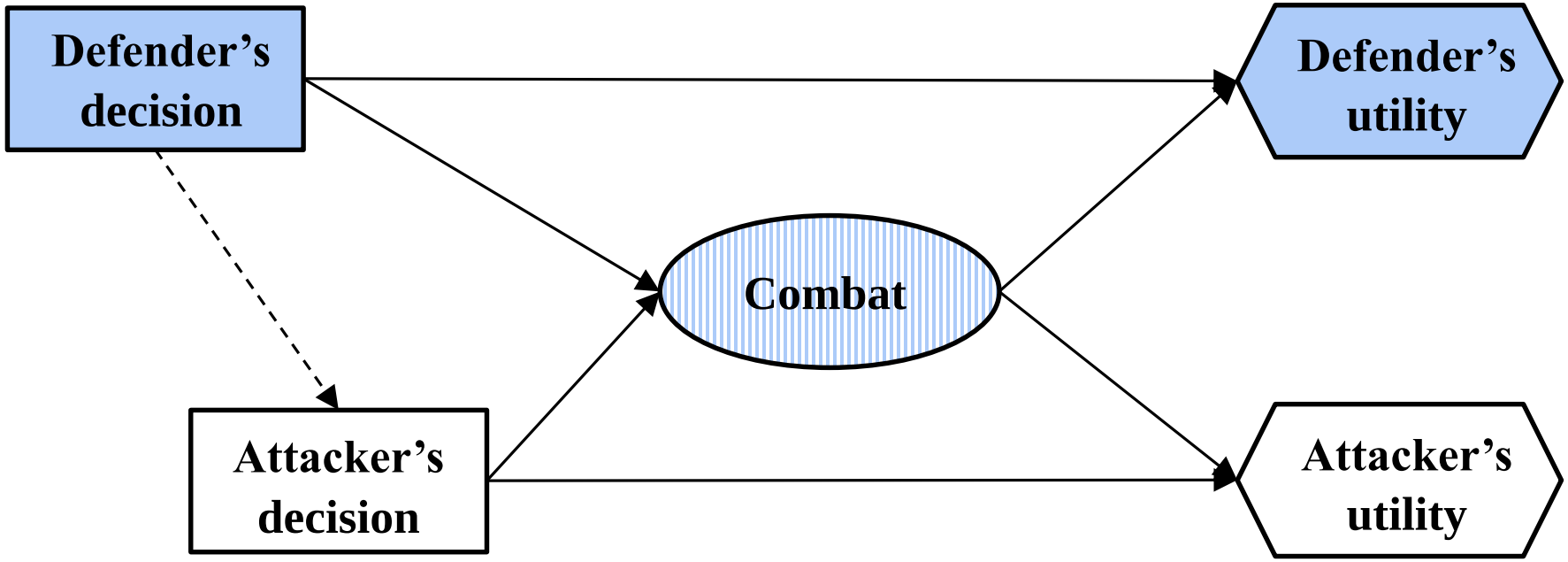
Assessing Portfolio Efficiency

- The utility functions may be difficult to elicit.
- Still, adversaries' decisions result in different probability distributions for the consequences of the combat.
- These distributions can be ranked based on adversaries' preferences for the consequences and some information about their risk attitudes.
- This serves to establish dominance relations among decision alternatives.

A Simple Example



An illustrative Example

- We examine the problem from the perspective of the Attacker.
- Defender has invested in fortifications.
- Attacker’s infantry company seeks to capture the position held by the Defender.
- Attacker can support its infantry with indirect fire by using artillery, missiles, strike aircraft or some combination of them.

Initial Analysis of Fire Support Portfolios

Fire support	Cost / k€	Support success probability	Defender casualties	Attack success probability
Nothing	0	-	None	<1%
Artillery	10	100%	Low	<50%
Missile	200	100%	Medium	>90%
Artillery+Missile	>200	100%	Medium	>90%
1 Strike aircraft	100, or >10000 if aircraft is lost	90%	High	>99% after successful support
1 Strike aircraft + Artillery	>100, or >10000 if aircraft is lost	90%	High	>99% after successful support
…	…	…	…	…

Initial Analysis of Fire Support Portfolios

Combining artillery with other fire support alternatives does not produce additional benefits and costs more, so these alternatives are eliminated.

Fire support	Cost / k€	Support success probability	Defender casualties	Attack success probability
Nothing	0	-	None	<1%
Artillery	10	100%	Low	<50%
Missile	200	100%	Medium	>90%
Artillery+Missile	>200	100%	Medium	>90%
1 Strike aircraft	100, or >1000 if aircraft is lost	90%	High	>99% after successful support
1 Strike aircraft + Artillery	>100, or >10000 if aircraft is lost	90%	High	>99% after successful strike
…	…	…	…	…

Introducing Attacker's Preference Information 1/2

- Attacker is risk neutral or risk averse about the cost of the fire support.
- The success of the attack is much more important to the Attacker than the Defender's casualties.
- This eliminates the alternative with one strike aircraft.

Fire support	**Cost / k€**	**Support success probability**	**Defender casualties**	**Attack success probability**
Nothing	0	-	None	<1%
Artillery	10	100%	Low	<50%
Missile	200	100%	Medium	>90%
1 Strike aircraft	100, or >10000 if aircraft is lost	90%	High	>99% after successful support
2 Strike aircraft	100, or >10000 per aircraft lost	99% at least one succeeds	High	>99% after successful support
…	…	…	…	…

Introducing Attacker's Preference Information 2/2

- The attack must succeed with more than 90% chance.
- Additional fire support is does not pay off once the probability of successful infantry attack reaches 98%, because 100% cannot be achieved in reality.

Fire support	Cost / k€	Support success probability	Defender casualties	Attack success probability
Nothing	0	-	None	<1%
Artillery	10	100%	Low	<50%
Missile	200	100%	Medium	>90%
2 Strike aircraft	100, or >10000 per aircraft lost	99% at least one succeeds	High	>99% after successful support
1 Strike aircraft + Missile	300, or >10000 if aircraft is lost	90% the aircraft succeeds	High	>99% if aircraft succeeds, 90% otherwise
…	…	…	…	…

Challenges

- Dominated decision alternatives may not always be found without specific preference information.
  - Using utility functions can be easier at times.
- Determining the probabilities of different consequences can be calculation intensive.
- Not suitable for situations in which the number of possible consequences is very high.

Advantages of This Approach

- No need to elicit the adversary's utility function.
- Consequences are often strongly correlated in combat.
  - Winning a battle also often results in lower casualties.

  → It is possible to identify dominated alternatives and with limited preference information..
- Does not have to rely on numerical analysis.

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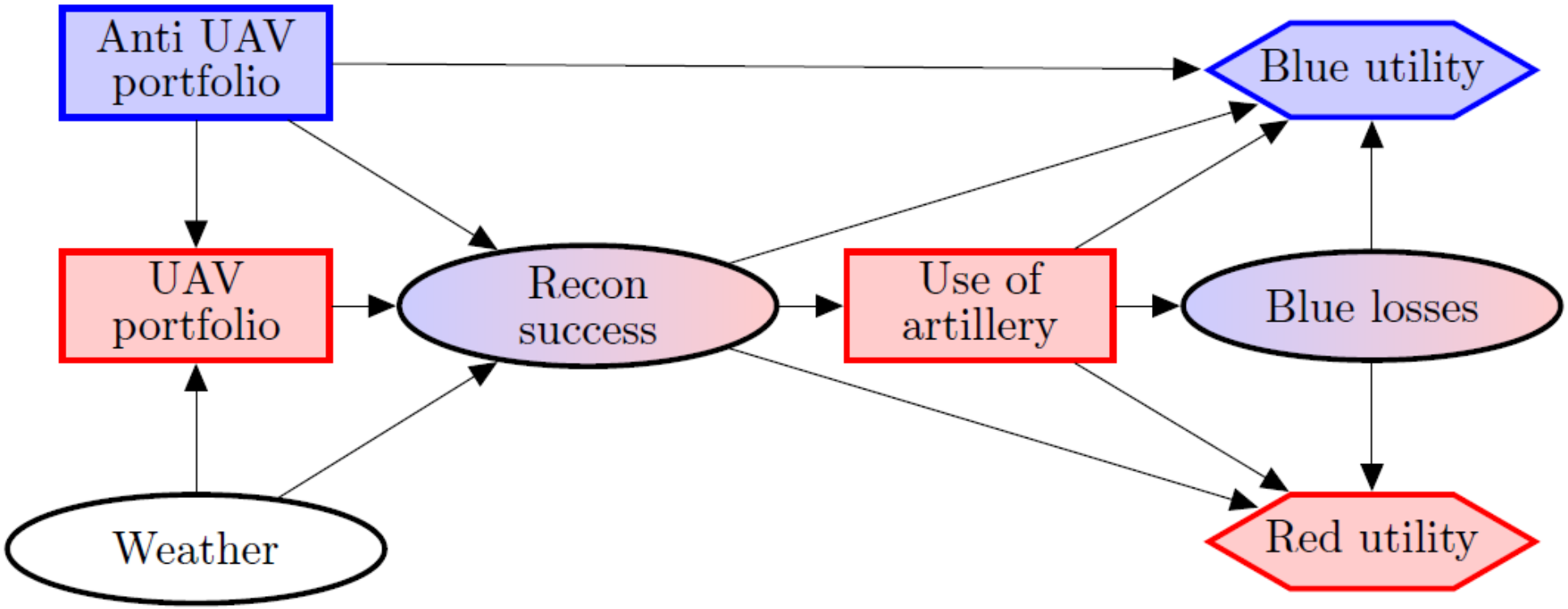
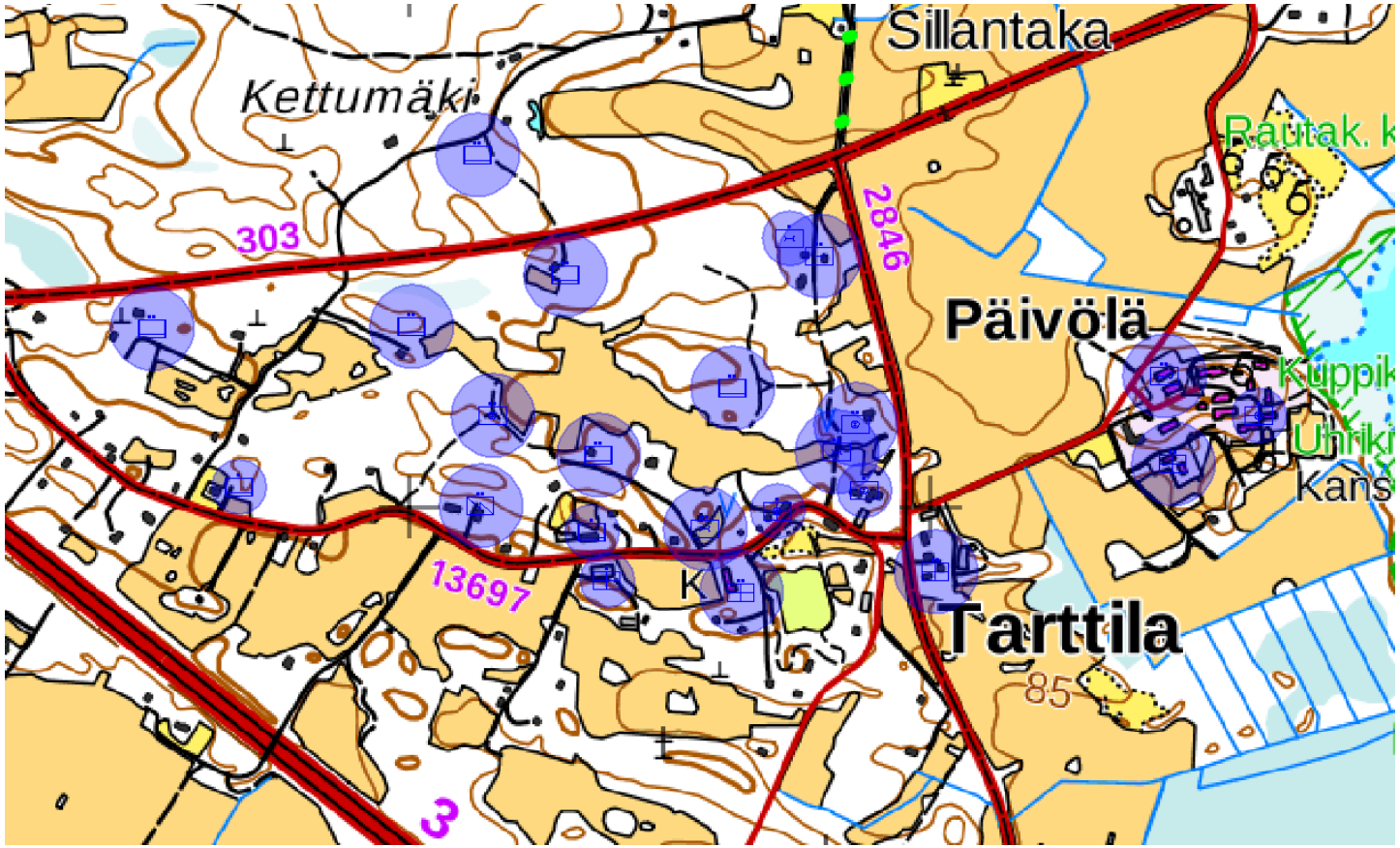
Protecting a Supply Company against UAV threat

- A supply company has established a supply center in the village of Tarttila.
- The Attacker knows the company is there and uses unmanned aerial vehicles (UAVs) to acquire targets for the artillery.
- Depending on the success of the target acquisition the Attacker will determine the most efficient way to use artillery fire against the company.
- Before the Attacker performs the reconnaissance the Defender can invest in various countermeasures.

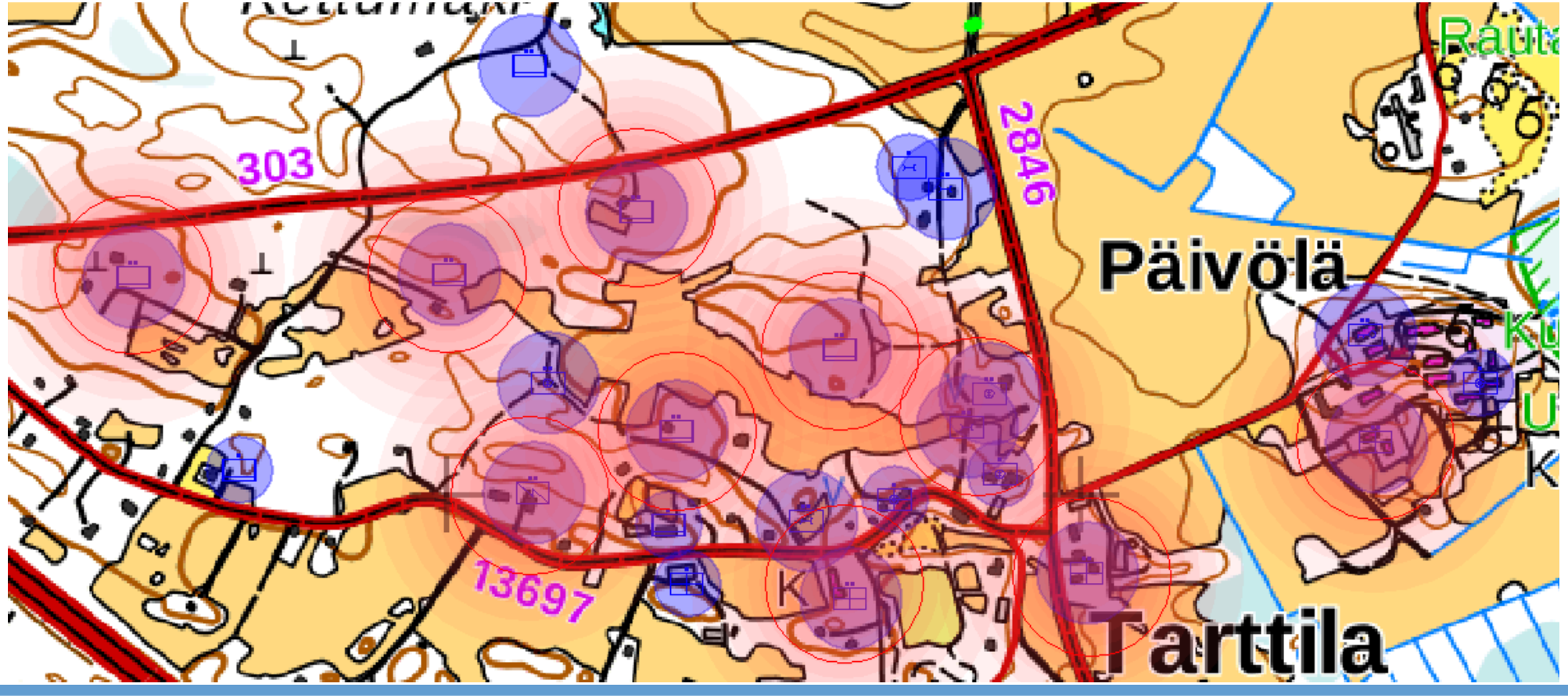
Influence Diagram



The Supply Company



Supply Company under Artillery Fire



Finding Effective Countermeasure Portfolios

- We calculate the benefits of different countermeasures using two different simulators applying datafarming techniques.
  - Sandis
  - Mockup UAV-simulator
- We rank the countermeasure portfolios by iteratively adding more preference data.
- The end product of the analysis is a list of non-dominated portfolios and a conditional ranking order.

Current Progress

- Effects of artillery fire have been calculated.
- UAV mockup simulator is still under development.
- Comments and ideas are welcome!

Acknowledgements

- Our research project is funded by the Scientific Advisory Board For Defence, which operates under Finnish Ministry of Defence.

- Finnish Defence Research Agency has provided us with military operation analysis tools.

Relevant Articles

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Thank you!

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