Risk Management in Asymmetric Conflict: Using Predictive Route Reconnaissance to Assess and Mitigate Threats*

Jason Lin[1], Benke Qu[1], Xing Wang[1], Stephen George[2], Jyh-Charn Liu[1]

[1] Texas A&M University, College Station, TX
{senyalin,berkerley,xingwang,liu}@cse.tamu.edu
[2] U.S. Department of Defense, Washington, D.C.
ticom.dev@gmail.com

Abstract. On the basis of the MECH (*Monitor*, *Emplacement*, and *Command/Control* in a *Halo*) model, this paper presents novel computing algorithms to evaluate locational values for attackers to launch improvised explosive device (IED) vs. direct fire (DF) attacks. A direct application of the system is to assess the environs of past incident locations for extraction of patterns. A *study area* R can be an isolated location, an area, or a route. For a given R, its proximity P can be mapped to explore noticeable characteristics associated with the IED/DF incident locations. For more advanced modeling purposes, a wide range of measurable parameters can be fit into the MECH model for tactical value evaluations. Within the distance constraints of the Halo, the attackers may optimize their location choices based on their risk preference. The tactical values of a location are measured based on the defensive/protective value, as well as the offensive value that it could offer to the attacker. A simple optimization formula is proposed to support flexible representations of risk preferences of the attackers in ranking of locations for the M, C and E functions across R.
Several case studies on major corridors find different patterns, but a significant number of them were found near or at local maxima of the measurement *route exposure.* It is also used to map the viewsheds of improvised explosive device (IED) vs. direct fire (DF) in rough terrain on the mountain. It was found that IED sites tend to have good visibility and more uniform line of sight (LOS) distances. On the other hand, most DF locations are near the boundary the viewshed, suggesting careful selection of the sites to provide cover in the attack.

Keywords: Asymmetric warfare, Optimization, Simulation, Risk aversion

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1 Introduction

Over a decade of military conflicts in the Iraqi and Afghanistan highlight that fact that roadside attacks launched by insurgents were among the most lethal tactics against the well-equipped allied forces. In these attacks, the insurgents (red team) emplaced an IED at a selected location, observed the movements of the troops (blue team), and detonated the device when the victim reached the blast range of the device. Hidden in well covered locations, insurgents also used IED attack to launch a direct fire ambush.

Essentially, the red team used the terrain around these attack locations as a force multiplier to shape the attack in asymmetric conflicts (AC). Objectively, an ideal attack location offers the red team best covers and good visibility to monitor the blue team movement and control the IED devices. The control position will also need to be within its own weapon range, while being protected by the terrain from the return fire of the blue team. Given that every individual has his/her perspectives about the significance of risks vs. rewards that often used in economic model [5,6], a sound modeling approach should allow incorporate any or all of these factors. It should also support reasoning of the most possible attack configures for past incidents in order to further explore the behavior patterns of the red team.

On the basis of the Monitor, Emplacement, and Command/Control in a Halo (MECH) model [1], we propose in this paper an interactive computing framework to support tactical risk analysis based on *visibility* and *covers*. For study area R and its proximity P, the analysis may be initiated from the perspective of R towards P, or from P towards R. The system also supports visual inference of viewsheds and blockage at and around known attack locations. Fusion of different reasoning approaches would provide a tool for higher level reasoning of red team tactics, such as “where may be the best locations to launch direct fire (DF) attacks to a route location X?” Or, “where might be the control locations of an attack location?”

2 Related Work

In an early warfare game model [9], Lanchester proposed that the combat power of a military force is the square of the number of units. Later Deitchman [13] modified the conventional warfare model to describe guerrilla asymmetric warfare. The term “force multiplier” is often used in military as a factor that enhances the effectiveness of a force. Some works [10-12] focus on terrain analysis to determine the optimal conditions for certain operations. In economics and finance, risk aversion refers to the human behavior that tends to favor less risky and more conservative investment portfolios [8]. A concave curve function between wealth and the utility of money implies a more risk-averse investment behavior [2]. Based on prospect theory [7], studies in [3,4] suggest that human decisions are made based on risk analysis.

3 MECH Behavior Model and Tactical Risks

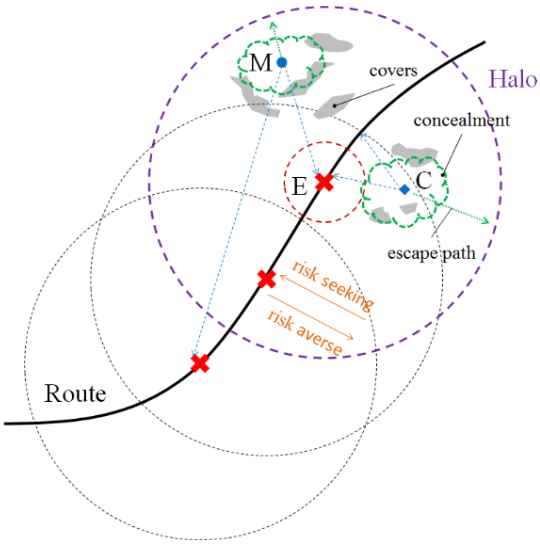


Fig. 1. Halo tactical level factors for risk preference modeling

The tactical risk analysis of a study area like a route R needs to consider both R and its proximity P. The baseline MECH model illustrated in Fig. 1 is a representation of the locational relationship between the red team at some location(s) of the proximity P of R, on which the blue team needs to travel through, where an IED is located at the center of the Halo. In the design of the computing framework, we aim to support two key analytics features: (1) flexible expressions of different risk preferences for the red team, and (2) automated reasoning about the tactical risks for the M/C and E locations. Generally speaking, any tactical operation needs to have both offense and defense tactics. It is important to note that distances play a key role in the tactics analysis. The Halo radius defines the maximum distance of concern with respect to an IED (victim) location, within which the red team has the freedom of placing its monitoring and control positions. For area wide assessment, the tactical analysis is based on comparison of locations on their abilities to observe or block points with the study area. When the study aims to reason about the proximity of an incident location, the study area can be defined as a local zone around the location.

The *visibility* of a location p_y at P is the sum of the LOS between p_y and all R points. It essentially gauges how easy it is for p_y to monitor or control any r point on R. It is an offense measure for the red team. A *cover* for p_y is a patch of area at its nearby location that has no LOS to R or r, depending on the context of the discussion. It is a defense measure for the red team. Firing ranges of the red and blue teams, device control range and blast range form the distance constraints as well as the risk factors for the red team to shape the attack. Concealment is defined as the degree of blockage between p_y and R.

To incorporate a broad range of risk preferences of the red team in making their planning choices, we propose a composite utility function U based on the weighted sum (+) or product (×) of the offense utility U_O and defense utility U_D. In the first (second) case, the offensive and defensive functions have additive (multiplicative) effects to each other. The risk preference of the actor is represented by the weight coefficients of the two types of functions ω_O and ω_D, $\omega_O + \omega_D = 1$, respectively. As such, we get $U = (\omega_O \cdot U_O \Delta \omega_D \cdot U_D)$ as an initial format of the tactical utility. As a qualifier, a location cannot be considered for action if either of its U_O or U_D is below some thresholds. In summary, we obtain a general utility function for an attack based on specific risk preference:

$$U = S_O \cdot S_D(\omega_O \cdot U_O \Delta\omega_D \cdot U_D),\ where\ \ S_O = \begin{cases} 1, & if\ U_O > \tau_O \\ 0, & otherwise \end{cases}\ ,\ and$$
$$S_D = \begin{cases} 1, & if\ U_D > \tau_D \\ 0, & otherwise \end{cases}$$

The utility function for an operation can be further decomposed as $U = S_O \cdot S_D(\omega_O \cdot U_O \Delta\omega_D \cdot U_D) = S_O \cdot S_D[\omega_O(F_M \Delta F_T)\Delta\omega_D(F_C \Delta F_H)]$, where F_M is the score function for observability, F_T aiming, F_C concealment, and F_H cover. The four score functions are normalized from their physical measurements to the percentile scale $[0{,}100]$ as utility of such score.

To reduce the computing cost of observability, we compute the viewshed $VS(r_x)$ for discrete points $r_x \in R$ at fixed intervals. For a point p_y in P, its observability score (F_M) is

$$F_M(p_y) = \sum_x LOS(r_x, p_y),\ r_x \in R,\ and\ LOS(r_x, p_y) = \begin{cases} 1, & visible \\ 0, & invisible \end{cases}$$

In contrast to the observability score, the concealment score of p_y is defined as the sum of points within the radius of γ that are invisible to a specified E location r_x.

$$F_C(p_y) = \sum_i {}^\wedge LOS(r_x, p_i),\ \ r_x \in R, p_i \in O_\gamma(p_y),$$
$${}^\wedge LOS(r_x, p_i) = \begin{cases} 1, & invisible \\ 0, & visible \end{cases}$$

This definition is not extended to R because it is assumed that physical engagement can occur only within the radius of the Halo. The *aiming* score is defined as the cumulative LOS for adjacent θ points approaching r_x: $CV_\theta(r_x, p_y) = \sum_x^{x-\theta+1} LOS(r_x, p_y)$. The aiming score F_T for p_y over the route R is simply $F_T(p_y) = \sum_x CV_\theta(r_x, p_y)$. On the contrary, for each route point (target site) r_x, we can evaluate how clear it can see the surrounding environ which also implies that how it is exposed to the surrounding area in the Halo with respect to r_x. Such exposed score $EXP_{d_{max}}$ can calculate as $EXP_{d_{max}}(r_x) = \sum_i LOS(r_x, p_i), r_x \in R, p_i \in O_{d_{max}}(r_x)$, where d_{max} is the maximum radius for the Halo with respect to the location r_x. However, for the attacker's prospective, to target on a designate attack location, they will normally site at the location of escape adjacency (EA) in order to move quickly from visible to hidden with regard to the target's location(s). Since the world's longest sniper kill is 2.47 km, an adjustable variable d_{fire} is defined as the fire range within 2.5 km. With a possible blast range d_{min} for

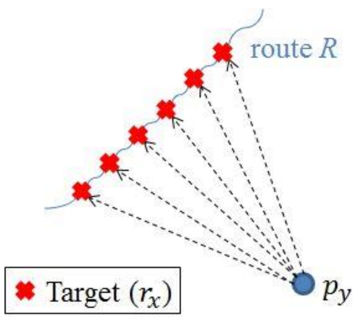


Fig. 2. Observability of target aiming

an IED (0 for a DF), the region-of-interest (ROI) also form a Halo annulus as shown in Fig. 3, which the actual exposure rate in considering the opponent's behavior of location choice is evaluated as $F_{exp}(r_x) = \sum_i EA(r_x, p_i)$, $r_x \in R$, $p_i \in O_{d_{max}}(r_x)$, and $EA(r_x, p_i) = \begin{cases} 1, & p_i \text{ is on EA} \\ 0, & p_i \text{ is not on EA} \end{cases}$.

A cover is a location which has no LOS to r_x, large enough for the attacker at p_y to run for it and hide within as needed. The cover score F_H is thus measured by the sizes, number of covers and their distances to p_y.

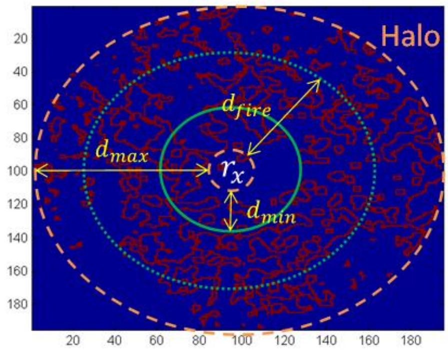


Fig. 3. The Halo model of evaluating exposure rate (red path is the escape adjacency with respect to the location r_x)

Tactical reasoning can be largely grouped into two types: the environmental behavior (R→P) module and the route-based behavior (P→R) module. The former one calculates the tactical value of a location x in R to get the potential Monitoring/Command locations in P. The latter one calculates the tactical values of R locations with respect to the given set of P points to derive the potential high risk locations on R.

For R→P, risk points indicate the highly possible locations that have insurgents to monitor or control the timing of the attack on route. For P→R, high risk points indicate locations in R that are most exposed to P. These two modules can interactively execute to address to some specific tactical question. For instance, given the best long-term *Monitoring* location $y \in P$, where is the best location x to place an IED on R? To answer this question, R→P is introduced by taking the selected route as input R points to calculate the best P point to get the best long-term monitoring point y. Subsequently, take y as the input of P→R module, and calculate the best IED deployment locations on R. Due to some spots really have the tactical advantage of setting an IED or execute DF attack, from the observations, it also allows us to interpret how the red team may reuse some spots for repeated attacks and run.

4 Case Studies

An important element of our goal in this paper is to study and observe interesting insights on the observations of visibility pattern with regard to the distributed locations of past events. In this section, we will present some case studies on the route-level assessment and the incident-level assessment to learn about visibility patterns of environs of past IED and DF attacks. Using the data set from Afghanistan[1], a number of experiments were conducted to learn about the visibility properties under the MECH model. Using an idealized ambush model of the U.S. Army, an AC area used for ambush can be divided into the *kill zone* of the victim, the *mantrap* and blockage area for controlled access by the ambush team and its command. Based on the MECH model, we also add the *monitoring points* to watch the movement of the victims. The resulting model is illustrated in Fig. 4. In the following discussions we manually interpret and mark the probable areas for the kill zone, mantrap(s) and the monitoring point(s) of a study area, after the observability, route exposure and past incidents were generated by MECH.

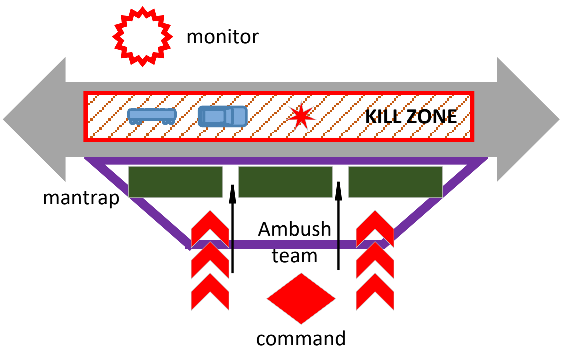
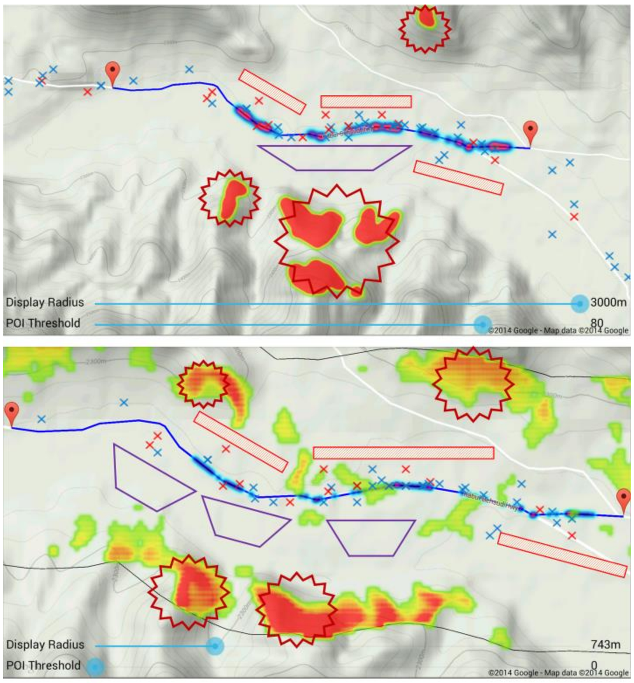


Fig. 4. An idealized ambushed model of military activity

Next, we consider route level study, where the red team is located at P, and the blue team R. Fig. 5 shows the locations on a long corridor with the highest exposures. Here, the two thumb pins define the area of study, and points with the highest exposures were highlighted by heat maps. The heat map overlay on the google map is rendered with the aid of the Google Maps Android API Utility Library and the assessment android app is built with Google Maps Android API v2. Past IED and DF events are also respectively highlighted on the map as blue and red cross-marks after the exposure map is first computed. In these cases, past incidents are found to be near at or near some local maxima of route exposures. We note that when we change the route range, the heat map locations may also change.

[1] http://www.fallingrain.com/world/AF/

A highway stretch near Kabul is used in the first study. In this case, we made a long range (3000 meter) observability study and the result is presented in Fig. 5. Then, we zoomed the map into a short range (800 meters) to assess the observability of the adjacent P points, exposure rates of the route, as well as the past attack locations. Next, we manually marked the kill zone (the high incident stretch), and top candidate areas for mantraps (purple lined trapezoidal blocks), and short range watch spots (red lined stars). It is worth noting that not all attacks occurred at the locations with the highest exposure rate. Instead, these locations (with high exposure rate) could be used as a signaling point for the attack to prepare for imminent engagement.



map center coordinate (34.4487, 68.7795)

Fig. 5. An example of route-level assessment in the valley along Kabul-Behsud Hwy: the red (blue) cross marks the IED (DF) events.

To observe if different traffic and terrain would lead to different observability patterns, we consider three types of areas: busy traffic regions, flat regions, and rugged terrain on the mountains. For the busy traffic area, we used two areas near the Jalalabad airport to analyze the studied routes as shown in Fig. 5. We observe that most attack locations are near locations with high observabilities. For several studied

map center coordinate (34.4112, 70.4924)

Fig. 6. Observability of the proximity around attack locations near the Jalalabad airport

corridors near rough terrain, both locations of frequent and infrequent attacks appear to be near or at high exposure road locations. It is also interesting to observe that several, if not most of the attack locations are also situated near the boundary of high visibility vs no or low visibility area.

The example shown in Fig.7 does not fit the idealized ambush model in Fig. 4. On the other hand, it appears that a good number of high visibility spots together form a grid to watch travelling victims and then the attack team take actions at or near locations adjacent to some local maxima of visibility.[2]

map center coordinate (34.4203, 70.4628)

Fig. 7. Heavy traffic area near the Jalalabad airport

Rugged terrain, like the mountain area, is noted for its rolling and rocky landscape. Quarters of the insurgent are predominantly and strategically situated and especially difficult of access, which will conceivably cause the U.S. army tremendous trouble to accurately pinpoint the insurgents and determine their tactics. So our analysis specially singles out two areas of this kind shown in Fig.8 as objects of study to try to make suggestive observations and seek interesting results. As the examples shown in Fig. 8, those attack locations tend to have large viewsheds, and they tend to locate at nearby the boundary of the viewsheds. The rough shape of the terrain makes it easy to create asymmetry in intervisibility between the red and blue teams, making concealment power a critical factor in shaping of the attack. What particularly interesting is the area in Fig. 8(b), which is a mountain area in the Nuristan Forest National Reserve between Jalalabad and Asadabad. Unlike the area in Fig. 8(a), this area has no valleys

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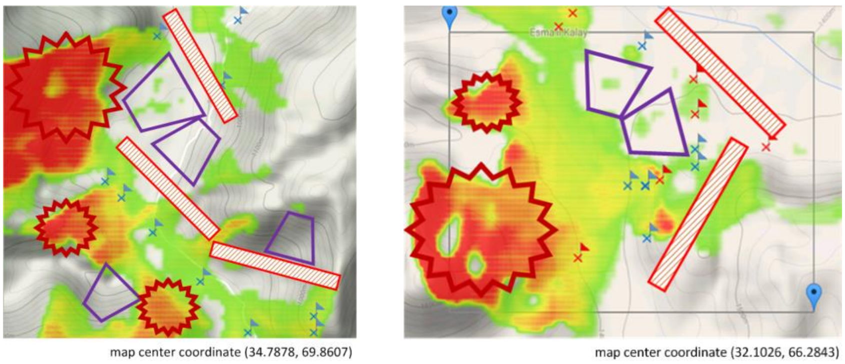
[2] The ASTER data product is courtesy of the online Data Pool at the NASA Land Processes Distributed Active Archive Center (LP DAAC), USGS/Earth Resources Observation and Science (EROS) Center, Sioux Falls, South Dakota (https://lpdaac.usgs.gov/data_access).

of open spaces; heavy vehicles by no means have access to this area, so conflicts happen in this area are conceivably based on DF-type guerrillas in which, the U.S. army may try to encircle and annihilate the insurgents. According to our observations, except that the incident locations predominantly are distributed at the border of the heatmap, they are of strong relationship in their time and physical continuity which bring out significant effect when we try to speculate on the possible kill zones.



(a) (b)

Fig. 8. (a) Mountain area2 near Esma'il Kalay; and (b) Mountain area in Nuristan Forest National Reserve between Jalalabad and Asadabad

5 Conclusions

This paper presents a computing framework to create tactical risk maps (TRM) based on the MECH behavior model. Through some studies of some representative cases, we found that MECH model could be used for extraction of terrain factors that shape the attacks. For some cases, the attack locations are strongly collocated with strong visibility, boundary of viewsheds, while in other cases the attack locations did not appear to have any relationship with nearby high visibility points. Given that the current model only considers elevations, the result suggests that other environs are being used to provide covers. On the basis of the computing framework, a wide range of large scale experiments can be conducted for high level situational awareness analytics, such as reasoning of tactical patterns, inference of safety shelters, and regional characteristics of attacks, so on.

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