Evaluating Positional Risk Through the Advanced Framework for Simulation, Integration and Modeling (AFSIM) Software

Undergraduate Honors Thesis

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By

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Abstract

Leveraging the computational power of modern computer systems to give the war fighter the edge is pivotal to the completion of Objective 1 of the USAF’s 2030 R&D strategy. The Advanced Framework for Simulation, Integration, and Modeling (AFSIM) simulates the varying levels of complexity that are necessary for a complete wargaming system. Evaluating the outputs of each scenario simulated by AFSIM is of critical importance to an operating analyst. A methodology of quantifying risk independently of its contingent components by their position in space and position with a state-space is proposed. The subsequent testing was performed to determine the viability of AFSIM to provide the necessary component information for the evaluation of positional data. An integrated air defense (IAD) scenario was created to be analyzed. A convergence study was performed to provide information on both the ability of the simulator as well as the balance to strike between computational time and the resolution of data. The initial conditions of the approaching units were rotated about the simulation to provide positional data points for the parameter of interest, death. The subsequent data was combined and plotted as absolute, or map position. Also, in the forms of a probability density function, and scope view. Analysis was performed to draw out directional and distance probabilities of interest. Data was also plotted against various moving units within the simulation to demonstrate capabilities of positional data to draw conclusions. Through proving AFSIMs capabilities to generate enough data to adequately assess the risk of a scenario, methods for which an operator can analyze the positional data is demonstrated.

Acknowledgements

I would like to thank my advisor Dr. Shawn Midlam-Mohler for the opportunity to do undergraduate research with AFSIM. My technical advisor, Dr. David Hillstrom, for his expertise in the simulator and for the guidance on approaching research itself. Without his previous work within AFSIM, the work performed here would not have been possible. To the many people, most notably, my roommate, Maxx Bowman, and fiancé, Emma Van Heel, for their patience in my explanation of the topic to clarify my own thoughts. Without your role-playing as rubber duckies, I wouldn't have been so thorough, *quack quack*.

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1. Introduction

1.1 Purpose

Ensuring an informed public, the National Defense Strategy (NDS), published every four years by the United States Department of Defense (DoD), describes broad objectives that the DoD will pursue. The most recent published NDS is from 2018. As part of these objectives, evolving innovative operational concepts is one of them [1]. The Department of the Air Force (DAF) then proceeds to make policy and timelines based off these overarching concepts. Published in April 2019, the *Science and Technology Strategy*, outlines these steps and objectives. The work performed here is in direct relation to the completion of Objective 1: Develop and Deliver Transformational Strategic Capabilities [2].

1.2 AFSIM Introduction

The Advanced Framework for Simulation, Integration, and Modelling (AFSIM) is a wargaming simulation framework. It is derived from Boeing's Analytic Framework for Network-Enabled Systems (AFNES). After research was conducted by Boeing between 2003 and 2013 on AFNES, Boeing decided against continuing, and all rights and source codes were transitioned to the Air Force Research Lab (AFRL) [3]. Since then, AFRL has maintained and improved the product into what it is today.

AFSIM provides the means to simulate wargames on various levels of complexity. Table 1 provides a means to understand the numerous scales that AFSIM can compute on. With these levels, new technologies can be created and tested, and their impacts or downfalls evaluated in shorter intervals. This technology is integral in the Digital Engineering Toolchain that allows for improved innovation timelines from draft stages to operational implementation [4].

AFSIM has its core in Monte-Carlo simulations to accurately reflect the many variations at all stages of decision making and interactions that can be had in a real-world simulation. An example on the implementation of this randomness, is in the interaction of objects and radar. There are many attributes that go into the recognizing and tracking of objects using radar. Using estimating equations and randomness, the ability of a modelled radar to not only detect but to also track is simulated.

Table 1: Levels of AFSIM Simulations [3]

Simulation Level	Complexity Scale	Time Scale
Campaign	Many v. Many	Days
Mission	Several v. Several	Hours
Engagement	One v. One	Minutes
Engineering	Subsystem Interaction	Seconds

2. Literature Review

Critical steps in the creation of a methodology involves the understanding of previous work performed in AFSIM and their connections to risk assessment. This chapter synthesizes information from multiples sources regarding these formulations.

At the core of the problem is the definition of risk within the framework of AFSIM. Risk as defined by Oxford Languages as a noun meaning ‘a situation involving exposure to danger’ [5]. This is a contextually based meaning and within a simulator such as AFSIM and other wargames, everything is in a situation that is at risk. In some areas, risk can be defined at levels. One means to define those levels in a wargame is risk to self, flight, package, and mission. The quantification of the risk within each level is critical.

2.1 Previous Research

Research performed by Connors et al. [6] in an Air-to-Air (A2A) combat simulation and the implementation of a new A2A missile determined five measures of effectiveness (MOE) to determine levels of risk and technology confirmation. These were: mission completion time, targets destroyed, weapon effectiveness, average weapons deployment distance, and blue vulnerability. These authors cite their choice of MOEs as a not uncommon practice within AFRL. Of particular note in this study, average weapons deployment distance and blue vulnerability defined as the number of red hits on blue units is of particular interest with their connection to positions relative to red units.

Attempts at creating an autonomous intelligence (AI) for A2A combat using fuzzy logic that could be introduced as a means to train pilots through the 'operator in the loop system' for AFSIM was performed by Ernest et al. [7]. The details are limited on the objective functions used by the authors, but some information is present. The authors attempted to quantify and surround the meaning of "good behavior". Values of which were implemented were: friendly kill shots, friendly misses, friendly deaths, friendly defensiveness, and enemy missiles fired. These values and others undescribed by the authors were fed to a fuzzy logic processor that learned means by which to accomplish tasks and react to enemy fighters actions. The preliminary outcome of this testing within AFSIM was described as successful in creating an AI that was quoted as being "the most aggressive, responsive, dynamic, and credible AI (he's) seen-to-date." The point of note taken from this research was the understanding that, again, values were determined by the designer of the processor and included objective values such as kill shots and misses.

A different approach was considered when finding sources of notable value for the definition of risk. Research was found by Hanlon et al. [8] that described the implementation of the control logic for an active target defense differential game. For this research, a Target-Attacker-Defender (TAD) scenario was created with multiple agents acting as Attackers and Defenders. The goal was in the creation of a scheme that would give Unmanned Autonomous Vehicles (UAV) the means to evade threats, or otherwise turn the risks to themselves and away from friendly units. In this scenario, the risk of the system is defined as target interception by an attacker which is to be reduced by the coordination of the defender to intercept the attacker before reaching the interception point. In this case, it is clearly defined that the risk of the system to be reduced is based on the position, speed, and direction of all agents within the system and the connection between them as 3-Dimensional movers in space.

2.2 Interviews

In addition to research conducted within AFSIM, interviews were performed with two active-duty officers with operational experience. The first interviewee, Lieutenant Colonel Emily T. Kubusek, is a KC-135 Command Pilot in the United States Air Force (USAF) and currently serves as the Operations Flight Commander at Detachment 645 at the time of interviewing. Questions were posed to determine the types of risk assessed in mission planning and execution as well as what determines mission success. Some conclusions drawn from this interview are that mission success criterion are highly subjective for each mission set. These parameters are determined by the planning officer of the mission using their expertise and experience in the field. What is determined as being the optimal solution rests on the hands of this officer. A notable point to be made is that the optimal solution of a mission does not always result in all forces returning home.

The second interview was performed with Lieutenant Colonel Michael R. Kelvington. He is a Ranger with the United States Army (USA) and has multiple years of operational experience. He currently serves as the Professor of Military Science and Leadership of the Buckeye Battalion. A similar set of questions were asked as in the first interview. Notably the evaluation of risk between USA and USAF is different since mission types and mission execution is performed differently. Similarly, though, mission success is defined by highly variable objectives by a higher headquarters that determines the risk-to-reward ratio for the mission. A force triangle was described, Figure 1, to explain the various areas where risk could originate and how they affect each other. Most notable is that risk to mission and risk to force can and are routinely defined and understood at mission execution. Strategic risk however can be described as an 'X-factor' to the mission that can invert mission status very quickly and often irreversibly. An example of this 'X-factor' is the happenstance occurrence of a beeper or other sound making device going off and pre-emptively making aware the enemy to the location of friendly forces. The mitigation and identification of this 'X-factor' is difficult to perform and highly variable. There are no size fits all solutions and is a hard quality to quantify.

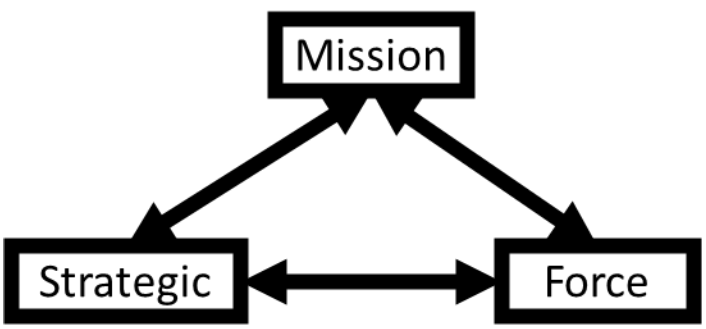

Figure 1: Risk Areas Triangle

2.3 Research Significance

As noted from the previous work done within AFSIM, risk is not clearly defined and highly subjective to the scenario at hand. Interviews of the active-duty officers further this conclusion by exploring risk outside of wargaming simulations and in the operational environment. With such broad and subjective definitions of risk, it is critical that there is a methodology to defining risk independent from the components that make it up. Equation 1 is a representation of how this could be quantified.

$$Risk = f(Position, State) \tag{1}$$

When evaluating the scenarios presented, two common themes appear. No matter the setup, there are agents that exist within the space of the simulator that have coordinates in that space as well as coordinates in relation to each other. There is also a state-space, actions to be taken, for which all agents contained within the simulation exist in. It is proposed that if a simulator such as AFSIM is capable of exploring both spaces, position & state, then an analyst presented with these results would be capable of quantifying risk in the way they see fit by defining the parameters of interest. The creation of this methodology would provide analysts a standardized means to compare differing parameters. The focus of this paper is on the creation and analysis of the positional data from AFSIM. The parameter of interest to be defined as risk is the death of the unit.

3. Methodology

3.1. Convergence Value

It is important in simulations that employ Monte-Carlo methods to reach convergence for the values of interest to be of statistical significance. However, there is a balance to be struck in the convergence percentage and computation time. In a simulator such as AFSIM, previous work has shown that it can be considered wide-sense stationary, as the output of the simulation is not dependent on the previous runs before it [9]. Also, due to the Law of Large Numbers, if sampled continuously, the simulation should converge to a value. However, this stability is not always the case. Previous work performed by David [9], implemented a normalized convergence scheme, Equation 2, so that as the number of runs approaches infinity, the value of the metric would approach zero. This implementation assumes a normal distribution and z^* of 2.576 which can be assumed if there are enough runs. Utilizing a z^* of 2.576 allows for the convergence interval to have a 99% confidence. It should be noted that the convergence of a simulation does not inherently mean convergence to the accurate value. It simply states that the simulation has reached a level of convergence to a number.

$$Convergence\ Interval = \frac{z^*\sigma}{\sqrt{n}\bar{x}} \qquad (2)$$

In this case in particular, the more converged a data set has become, the more positional data that is present. A case study needed to be performed to determine the level of convergence that would strike the appropriate balance. A normalized plot of the convergence rate of the scenario from one direction is in Figure 2. After comparisons of computation time, processing time, and data resolution were compared between the four levels of convergence, a convergence level that adequately satisfied all parameters was selected and used for all directions.

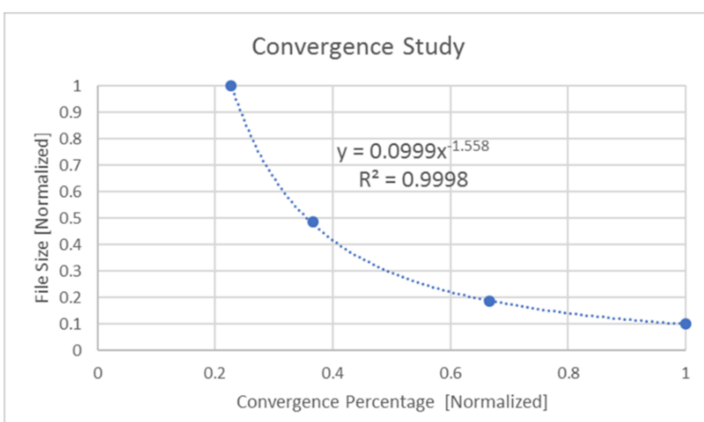

Figure 2: Convergence Study

3.2. Scenario Setup

The need to fully leverage the power of AFSIM was critical in the selection and crafting of the scenario. Some modifications were made to a demonstration scenario that's used for training purposes to show the capabilities of AFSIM. It is an Integrated Air Defense (IAD) scenario that can be characterized by multiple moving attacking agents, multiple moving defending agents, and multiple closely located static targets. A representation of the scenario can be seen in Figure 3.

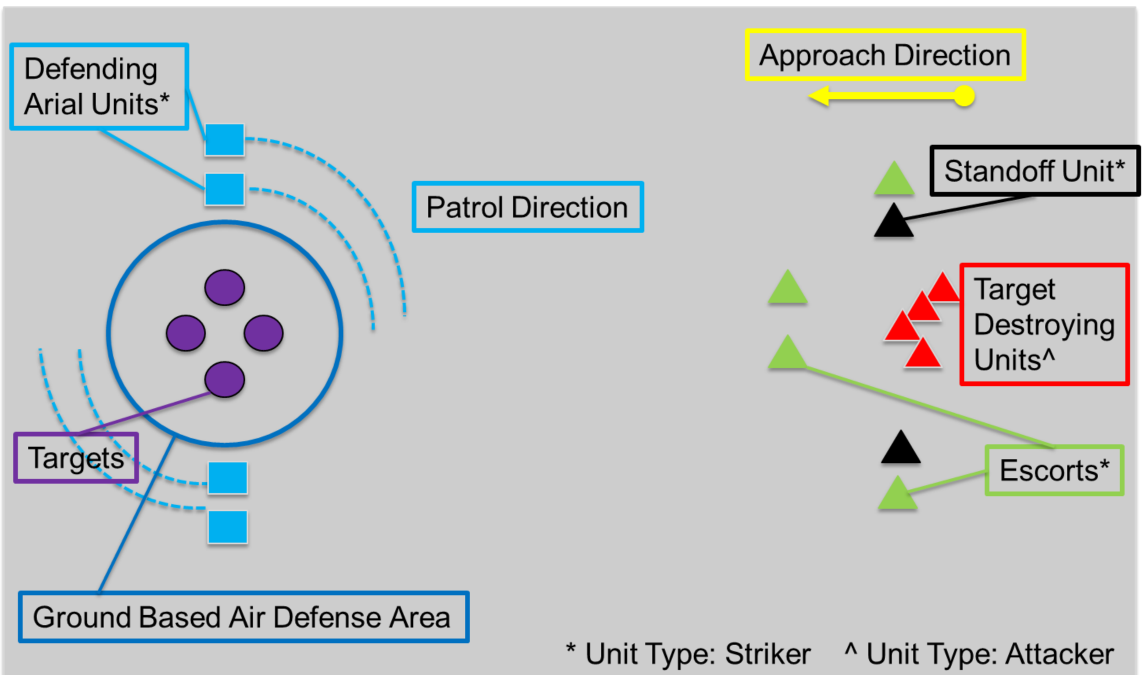

Figure 3: Scenario Laydown & Unit Composition

Modifications were made to the sample scenario to include the implementation of more complex behaviors to the striker type units. This would allow the agents to emulate more reasonable reactions by competent operators rather than following pre-determined tracks, like the attacker type, which would decrease the value of the resulting output. The scenario also incorporates command and control infrastructure, communications between agents of the same side, and path finding logic to attempt and avoid an area of known danger.

3.3. Data Generation

The same scenario, as described in Section 3.2, had the initial starting points of the attacking agents rotated about a central point located between the static targets. By performing this rotation four times, approaching from each cardinal direction, Figure 4.a, the simulation could explore different attack directions and populate data in different regions. The simulation was also performed at each of the sub-cardinal, or 45° off-axis, directions, Figure 4.b, to compare combined data sets. Each run otherwise remained the same. Once the simulation hit the convergence criterion, the results were saved for post processing and combination upon completion of data generation. The data sets were combined together to show a full picture as in Figure 4.c. Combing the data sets allows for a fuller picture of the different areas of risk.

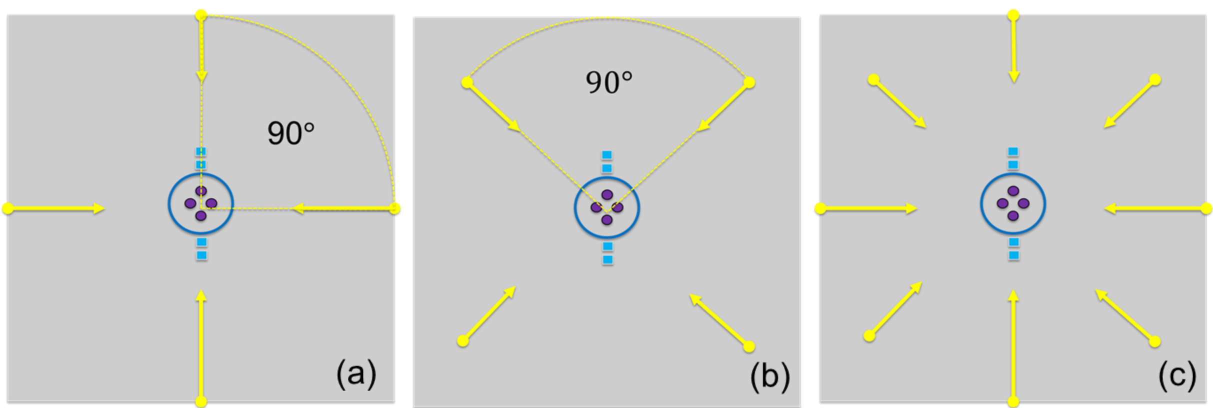

Figure 4: Data generation configurations for on and off axis approach directions for desired combined plot

Since data sets were to be combined, a study was done to isolate and show the potential overlays of the cardinal and sub-cardinal directions. By performing this isolation, identification of the interactions of the overlapping could be analyzed. An example of the laydown that was done to generate this data can be seen in Figure 5. This analyzation would also provide information on if 4 or 8 directions is enough to reflect enough information for an analyst to consider.

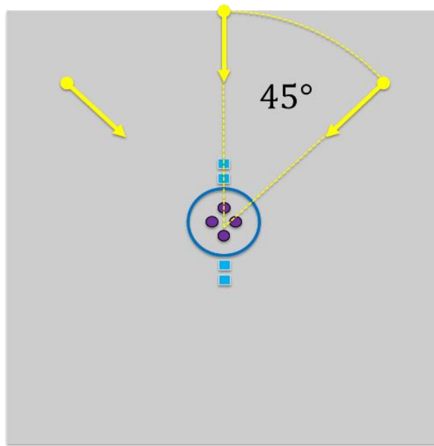

Figure 5: Data generation configuration of off-axis approach directions

4. Results & Discussion

The results presented were calculated using the exact values within each data set. Given that AFSIM is an International Trade and Arms Restricted (ITAR) software, the exact values generated cannot be presented and must be normalized. Thus, all plots have been normalized by the largest values to create plots ranging from 0 to 1 and -1 to 1 as appropriate.

4.1. Absolute (Geographic) Position Data

Absolute position is defined as the geographic position of the unit upon death. The aggregation of this data was plotted. In Figure 6.a, the attacking (red) units were plotted as well as the defending (blue) units. This view provides a general means to observe basic interactions between attacking and defending sides. This view also takes into account all units for each side. This includes any weapons shot or dropped in the scenario. This information does slightly skew the results shown to be focused around the areas were lots of armaments were expended and subsequently died. Identification of the symmetry in this figure also allows for an analyst to determine if the approach directions selected provide data of value. If there is a lot of symmetry, an analyst could potentially conclude that one approach direction should be isolated and further converged to perform further analysis on. In this scenario, there is no symmetry.

The sides can also be broken down into their corresponding units. That breakdown is in Figure 6.b. Each unit of the attacking force is assigned a different color to parse out the areas of interest for each. The color scheme noted in Figure 3 is followed to provide continuity. Each unit also has different behavior assigned to them and is therefore pertinent to have separated from each other. It should be noted that the behavioral traits assigned to each unit do not pre-define the routes but the reactions to external forces.

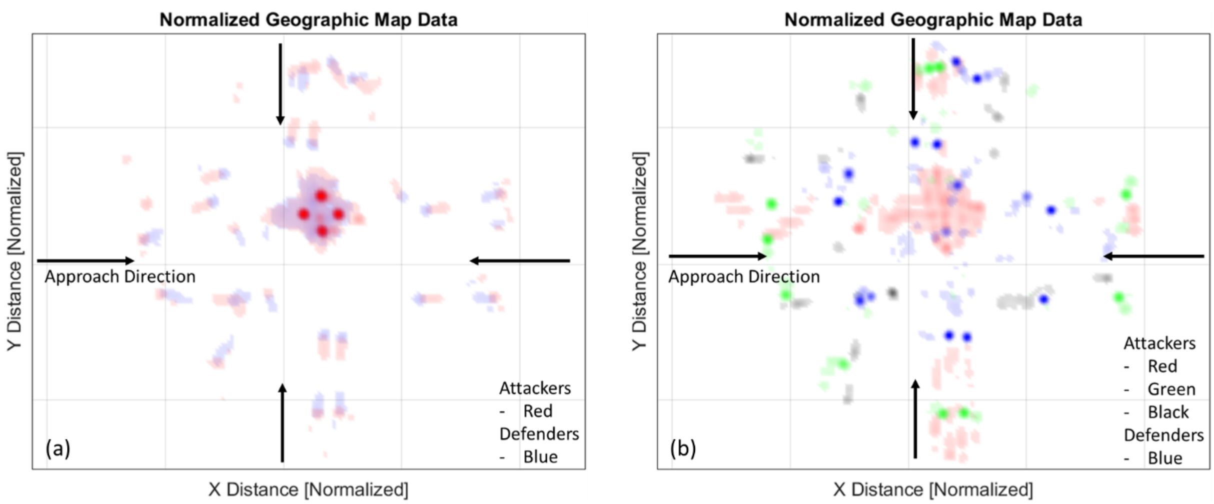

Figure 6: Cardinal direction absolute position plots with unit breakdowns

It can be seen from the Figure 6.b., that from each approach direction, there are some patterns that can be discerned. The data however is not symmetric about the vertical or horizontal axis. In this format, while understanding the context of the units in question, provides a means to estimate what potential interactions are happening in each area. For context of the situation, the red forces are led by green forces on the approach path, as shown in Figure 3. Of note however, there is noticeable number of red units dying after the locations of large green unit death. The black units are interesting as well. Considering their usage as a non-direct combatant in this simulation, there’s a noticeably lower amount of their death portrayed. From this observation, an analyst could ascertain that the black units are put at considerably less risk in this scenario than their green counterparts.

The data presented in this form, however, has its downsides. It is not efficient to review the plot to understand the spread of the risk along the radial axis. Compression of all the radial axes to a singular axis is desired to determine if there is reasonable distribution of data points. A probability density function (PDF) was chosen to display this data. The number of bins selected considers the resolution of the data present in the set.

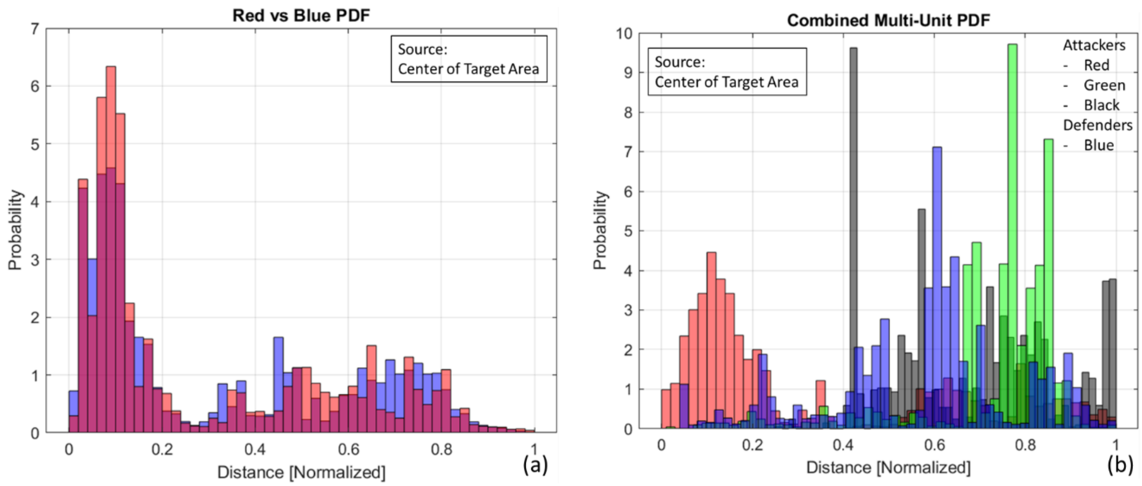

Figure 7: Probability density function of the multi-unit breakdown compressed on the radial axis

The PDF of Figure 7 is the representation of Figure 6 with the same color schema for the unit breakdown. The zero point, or datum, is selected as the center point of the simulation between all four stationary targets. Figure 7.a. demonstrates that the spread of the units is across the entire domain of interest for both the blue and red sides. Though in some locations the percentage probability is low, the values achieved do also provide some context for the locations at hand. To populate these areas more, an increased level of data resolution would be needed. Figure 7.b. however indicates that when it comes to specific units, the red units have an increased risk between 0 and 0.2 while the other aerial units are spread out between the distances of 0.4 and 1 from the datum. A breakout of this figure would be useful to ascertain if there is data for every unit on every point along the distance of reference. Considering the resolution of the data set, the answer to this question is "no" and could be solved with running the simulation to a more convergent level or combining more data sets. However, the data that is present indicates considerable peaks around certain distances that can be explored. A different version of the PDF with a different datum is desired and explored later. This comes from the understanding of the units at hand. The datum at hand no longer has its location based off of the absolute position on the map and therefore will be explained further in the next section.

4.2. Relative Position Data

Similar to the means by which absolute position was plotted in Section 4.1, relative positional plots can also be created. The process by which this was done was through determining the rays cast from a source to the unit of interest upon the event of interest. A visual explanation of this process can be seen in Figure 8. The method by which a ray was cast by the source was done by determining the unit to be the source, whose death would trigger the ray to be cast to the unit of interest.

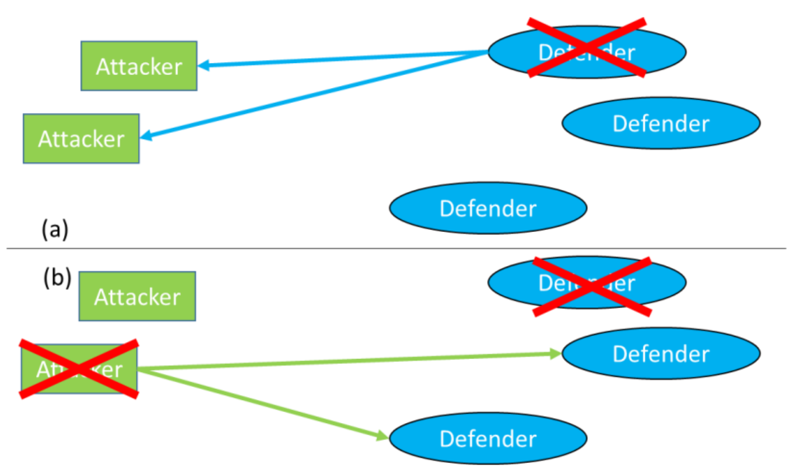

Figure 8: Ray casting visual explanation

When this happens, the rays cast are only from the now dead unit to the units of interest that are still alive in the simulation. Figure 8.a. demonstrates that if the defender is the source unit with the attackers as the unit of interest, what rays are cast. Figure 8.b. shows that if the same simulation were run and the source was the attacker and defenders are the unit of interest, the rays that are cast in that situation with an already dead defender.

An understanding of the interaction distances of the blue, black, and green units, all of which are striker units, above in Figure 7.b. is desired. Also, a demonstration on the selection choice of source and unit of interest is needed. Figure 9 provides this comparison. Figure 9.a. shows the differences between the blue and red sides as a whole. Within this figure, only the structures should be compared as the normalization of the distances within each subset do not allow for the distances directly to be compared. With this in mind, the structures are similar but demonstrate that the effect of time causes the data points to be slightly different and how the source and unit of interest desired should be carefully chosen.

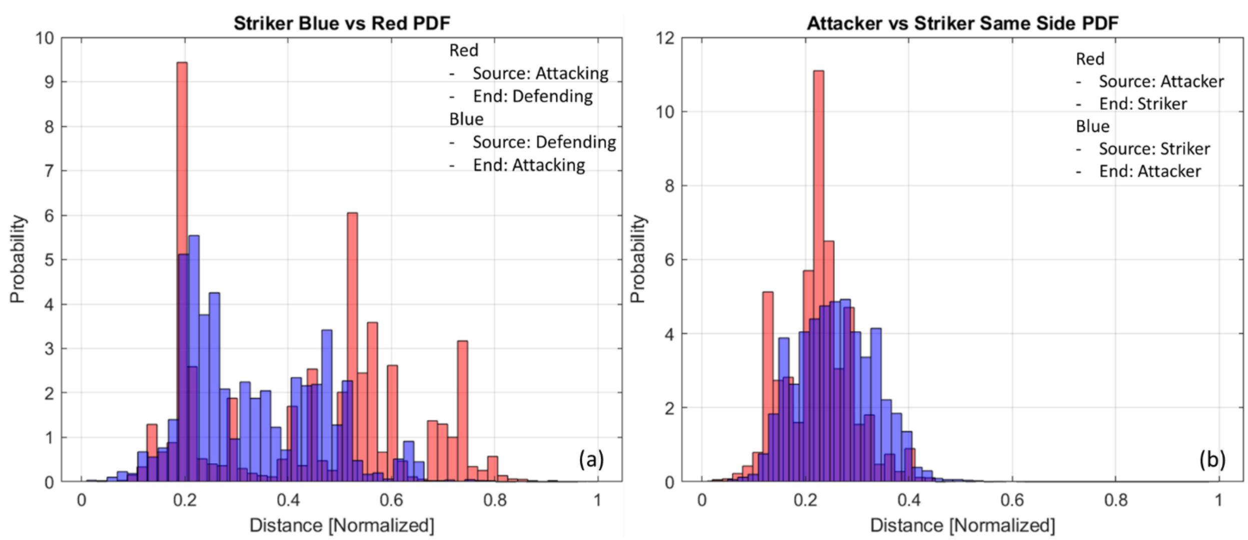

Figure 9: PDF breakout of striker units

This same phenomenon is to be noted in Figure 9.b. This figure demonstrates the comparison between the escort striker, green unit above, and the attacker, red unit above of the same side. When attacking units die and the rays are cast to the remaining escort strikers, there is a fairly normal distribution at a distance of 0.25. It is a slightly more normal distribution at a similar distance when taken from the perspective of the escort striker to the attacking unit. From this information combined with the information on the units and the laydown, that the escort units are dying near the escort distance and that when the attackers are dying, the escorts are still at their escort distance and have not made a move to block the attack. This analysis however is lacking in directional component information as to where in relation to the units are these deaths occurring.

This is where polar plots or scope views are needed. These views display information in a similar format as a density plot for the absolute position data. The difference however comes with the ability to choose a central datum, much like the PDF plots, and bin numbers to pull out more precise positions and probabilities of the event of interest. The number of bins selected for these scope views was determined based on the size of the data set. This view also demonstrates more accurately the need for large data sets so as to demonstrate the gradient fields more easily around each hotspot of interest. A breakdown of Figure 9.a. is shown in Figure 10.

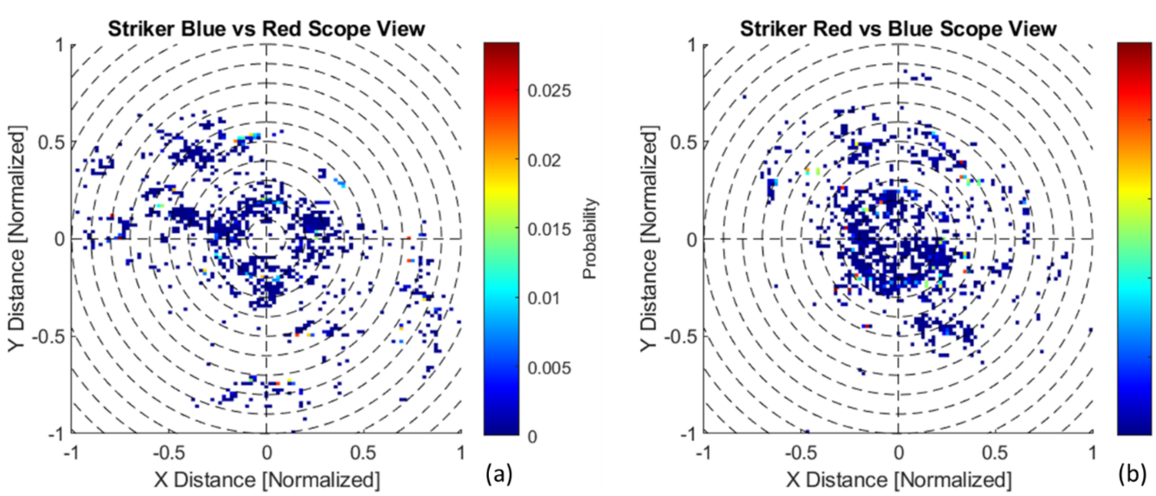

Figure 10: Scope view of strikers from the blue and red sides with comparative perspectives

This figure more accurately reflects the differences in perspectives. Figure 10.a. shows that the death of a blue striker occurs with most red strikers being present around a distance of 0.1 to 0.3. When compared though to Figure 10.b., it can be seen that the death of a red striker typically has a blue striker within 0.3 of the unit. There is a lack of a standoff range. It should be noted by the analyst that the scope view has its limitations. Since the rays cast by the source are indiscriminate of the unit of interest, as the distances gained go further from the center, more skepticism should be exercised as to whether to include those data points in the analysis. This can be more easily determined when normalization does not have to occur, and distances can be drawn directly and compared against the absolute position data.

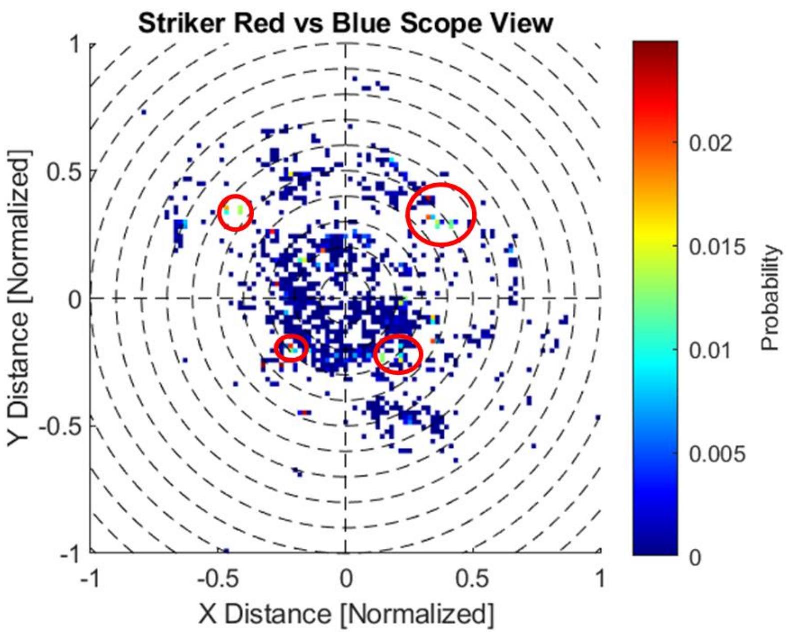

Figure 11: Striker red vs blue scope view with annotated hotspots

Taking the perspective of the red side, a further analysis can be performed. Figure 11 annotates hotspots that may be of interest to an analyst. Of note, these areas are approximately 45 degrees off the cardinal axes. Interpretation of this would be that a red unit should be wary of blue units approaching angles that are 45 degrees off their location at a distance of 0.3 and 0.5.

Notably, a red unit should also be wary that the risk to their self greatly increases once a blue unit begins breaks within a distance of 0.3.

It should also be noted by an analyst what units are plotted and their abilities to interact with each other. Figure 11 demonstrates a combination of all these potential interactions combined. Taking the position of a blue side analyst, Figure 12 indicates the differences in scope views when the ability to interact comes from only one unit.

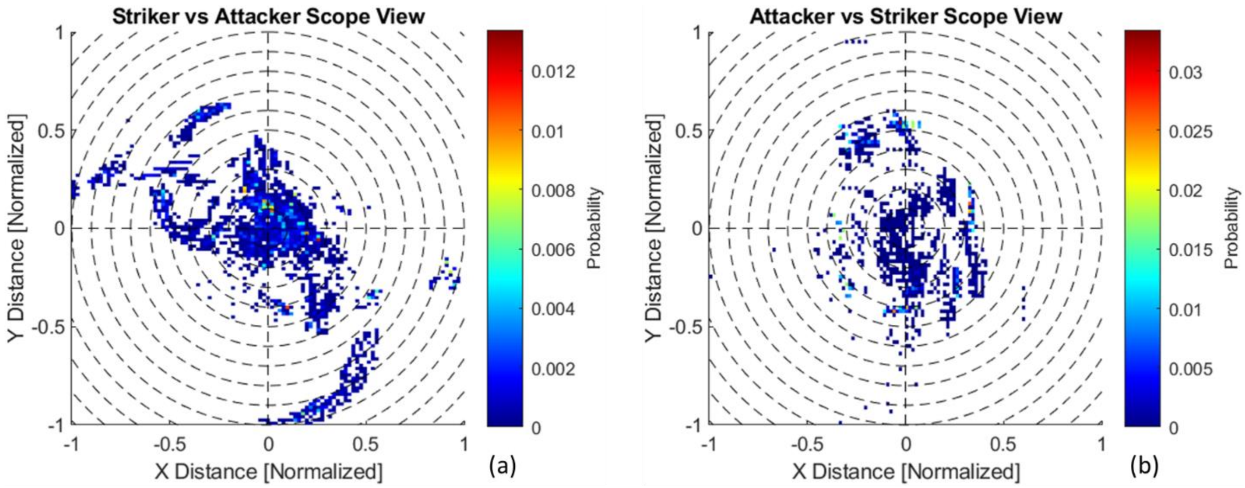

Figure 12: Demonstration of the differences between units where only one unit can interact with the other

Figure 12.a. is indicating that when a blue striker is within 0.2 distance and anywhere around it is a red attacker, the risk to self has greatly increased. This information can also be compared however with the information from Figure 12.b. Here, a red attacker consistently dies when a blue side striker is anywhere around it at a distance of 0.4. The distance itself can be more accurately compared when data does not need to be normalized. When observing the ring at a distance of 0.4 on Figure 12.b., it can be noted that there are higher concentrations of blue striker existing there when a red attacker dies. If the distances could be compared, an analyst could potentially determine that the lowest risk to a blue striker when taking out a red attacker comes from its ability to launch an attack at a certain distance. What the analyst would have to keep in

mind however is the two bands that are ‘swirled’ in Figure 12.a. Since the red attacker is incapable of causing this, another scope view would be needed, and the context of the situation evaluated to determine the true cause of this banding.

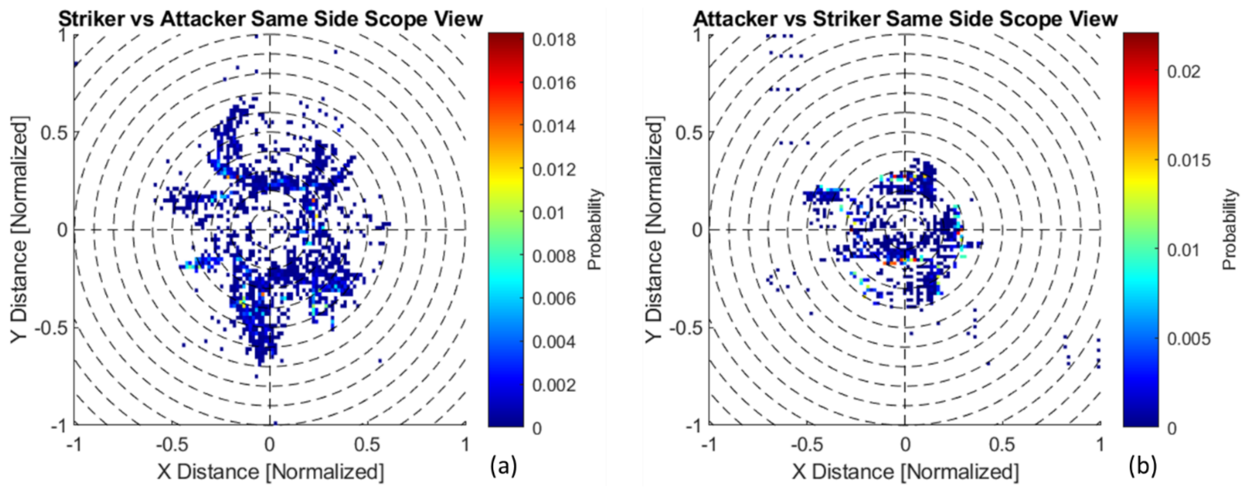

Figure 13: Demonstration of red side scope view of units with zero interaction

Just like there is the ability to plot views that have only one-sided interactions, so can zero sided interactions. The scope views of Figure 13 demonstrate this phenomenon. Taking the perspective of a red striker, otherwise escorting the red attackers, in Figure 13.a, it can be observed that the strikers appear to die in a ring that begins at a distance of 0.2 to 0.4 but also in peaks that extend beyond the edge of the ring out to 0.7. This can potentially indicate that the strikers are identifying threats to the red attackers and are extending out in attempts to neutralize the threat and failing. In Figure 13.b, when red attackers are dying most of the red escort strikers are within a distance of 0.4 of the escort strikers. An analyst given the true distances, could potentially ascertain that there are gaps in the network of escorts that are allowing blue strikers, the only unit capable of interacting with the red attacker, to attack and destroy red attackers. In this case, this can not be accurately assessed due to the normalization of the plots against different values in this paper.

4.3. North Study

The understanding of the effects of smaller changes in the increments of the initial approach directions is necessary to understand how many approach angles should be considered before determining an adequate number of angles have been tested. Figure 15 shows the density plot of the combined data sets of the study of the Northern approach directions. A quick view of the figure indicates that all are different. A breakdown of each direction as their own subcomponent can be seen in Figure 14.

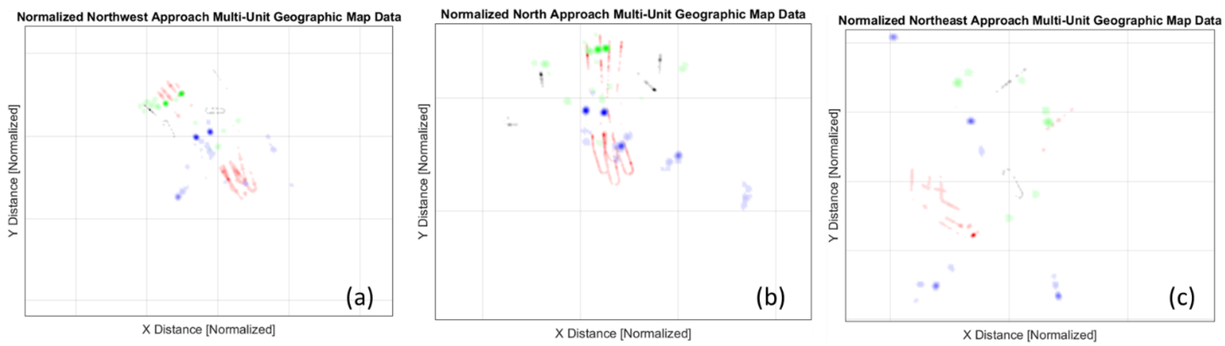

Figure 14: Multi-unit density plots from (a) Northwest (b) North (c) Northeast

Observing the differences between the three graphs is critical to the understanding of the interplay that each additional run at a different run would add to the total aggregate. Figure 14.a. and 14.b. appear to be similar at first glance but upon closer inspection, there are areas present in both that don't exist in the other. The general structure of each other is similar with unit specific hot spots moved around roughly the same areas. However, when observing Figure 14.c, the general structures observed in 14.a. and 14.b. are not present. What is most pertinent in Figure 14.c. is the spread of which the units are separated from each other when they die. This is a perfect demonstration of the necessity to add multiple directions together to adequately consider the variance of each direction. Of note, until the data points converge on the central targets, the unit death appears restricted within an arc relevant to their specific approach angle. Figure 14.c.

has an increased level of information outside of the relevant approach angle and is an example on how the simple change in the approach angles can demonstrate different results. At present, for the current scenario laydown, exercising 8 different approach angles is adequate enough to add data points to provide a reasonable analysis. The current directions develop information primarily within their own arcs and have information that interacts with other approaches to provide information on hotspots. Figure 15 demonstrates the combination of all directions.

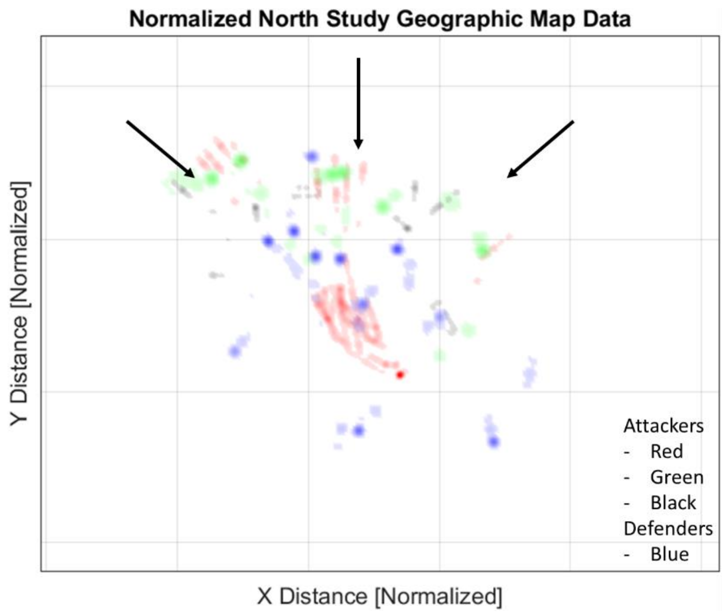

Figure 15: North study approach of off axis approach directions

4.4 45° Off-Axis

After demonstrating the connections between a cardinal direction and the corresponding off axis approach angles beside it, it is pertinent to explore the differences between the cardinal directions and the off-axis angles. Figure 16.a. demonstrates the striker versus attacker scope view explored earlier with the same scope view but using the information derived exclusively from the off-axis approach angles. Of note, the normalized distances plotted are very similar to each other. Similar structures appear in the views with variations. The inner circle of radius 0.4 contains a high level of information. This information allows for a correlation to be determined that within that distance, chances of death do increase in comparison to outside the circle. Also, a segment of an arc appears at in the south to southeastern portion of the scope view. Though Figure 16.b. is less dense, a structure is similarly present. In comparison, in the northeastern quadrant of Figure 16.b., there is more information. Similar information is present in the northwestern quadrant. This similarities and differences in the information provided from each set of 4 directions is indicative of the complimentary nature of running the simulation at varying angles. A combination of the two data sets would allow an analyst to draw conclusions more confidently due to each data set painting similar areas with data to increase probability. Much like how the data sets can overlap to indicate areas of high risk, once data sets are combined, an analyst can also confidently indicate areas of low or lower risk. As demonstrated in the North Study, an increase in the number of angles would be beneficial but would see a decrease in new information per run that would continue to aid an analyst in the confidence of the conclusions but at the expense of greater computational time.

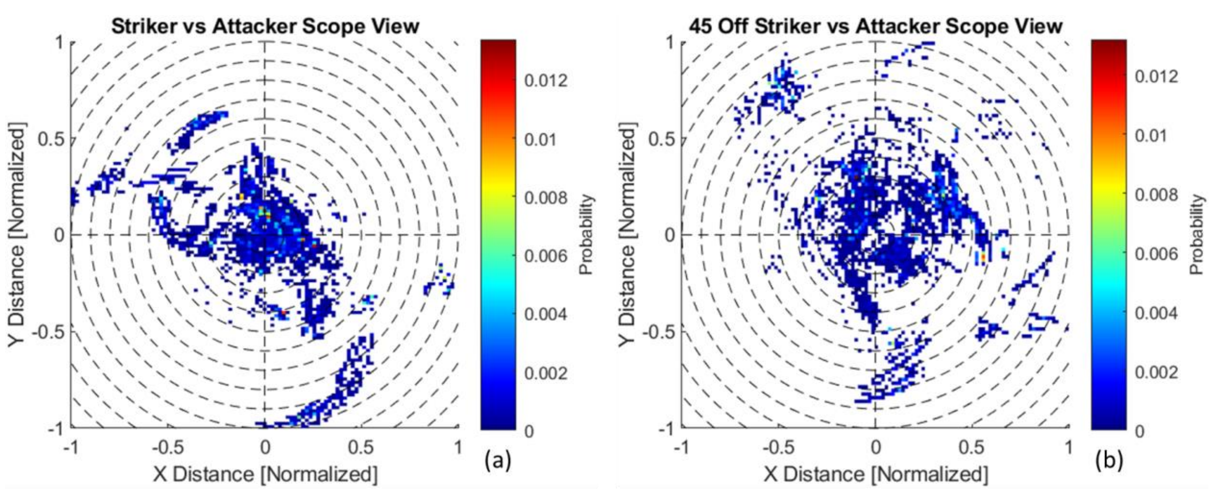

Figure 16: Comparison between cardinal directions and 45° off-axis directions

4.5 Combined Directions

Combining the information from each of the 8 directions into a singular data set gives an analyst more confidence in making decisions using the various tools previously used. Figure 17 demonstrates the density plots and their increased fullness. Figure 17.a. is the side versus side plot and shows that there is information present in all directions from the center of the four targets. A more useful plot however is Figure 17.b. with the multi-unit breakout. This demonstrates how there is lots of information present in each direction. From this plot, an analyst can potentially derive that at a certain distance from the center of the target area, blue and green units have increased levels of death.

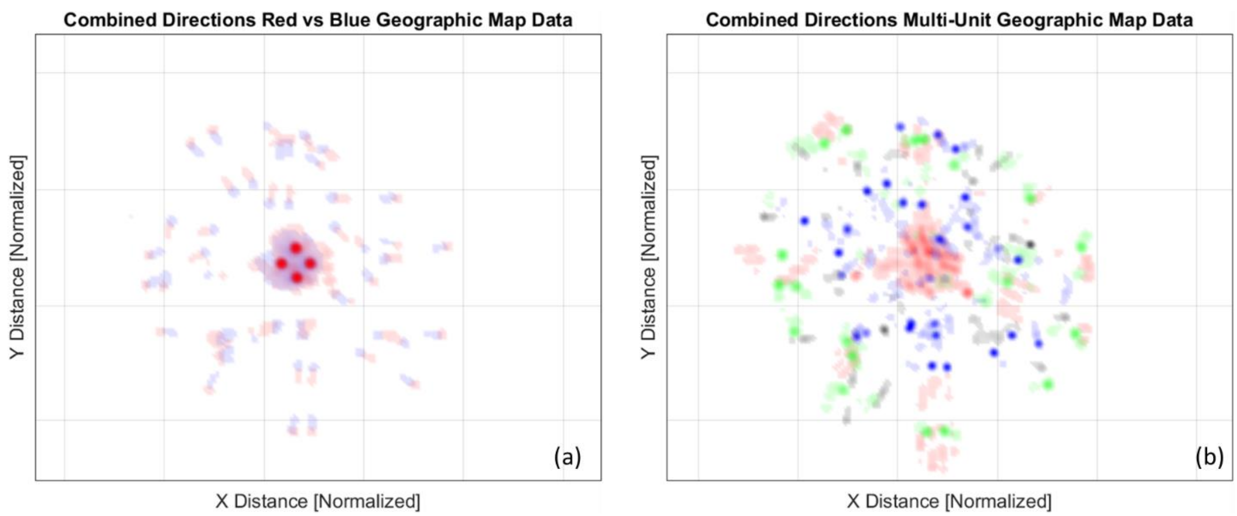

Figure 17: Density plots of all 8 directions combined

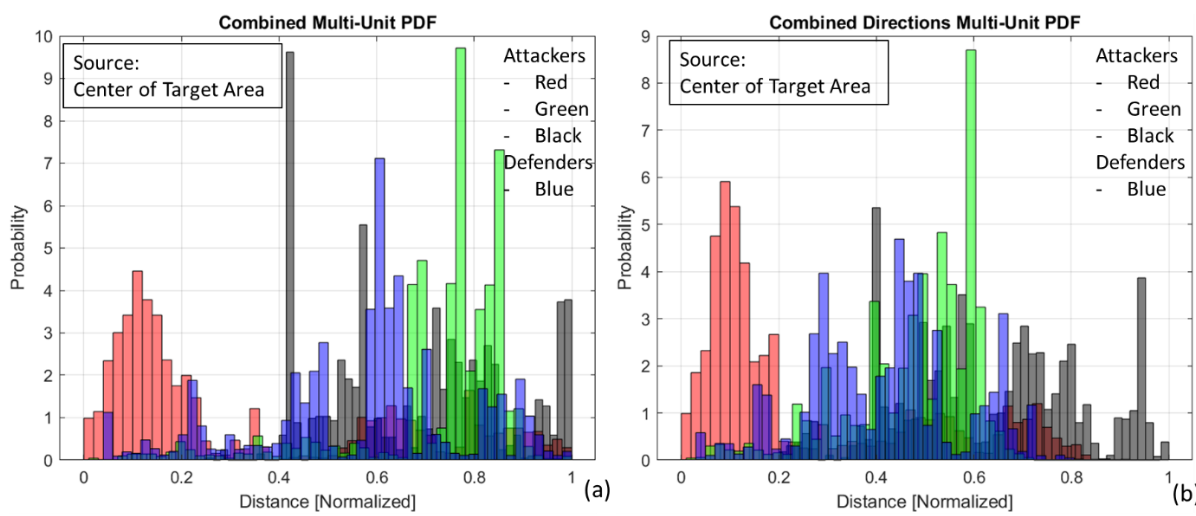

Figure 18: Multi-unit probability density function comparison between (a) 4 and (b) 8 directions

Probability density functions with the source at the center of the target area is the best way demonstrated to explore this information. Notably, even though the peaks demonstrated in Figure 18.a. are in similar position in 18.b. the values are not nearly as probable and have more information on either side of them. This increased information on either side is expected when combining data sets from different angles. An analyst can be more confident that in areas with peaks that are surrounded by increasing levels of death that the peak is truly a peak in the scenario and not a fluke of a single direction. Similar analysis and conclusions as drawn earlier can be drawn using the information from Figure 18.b.

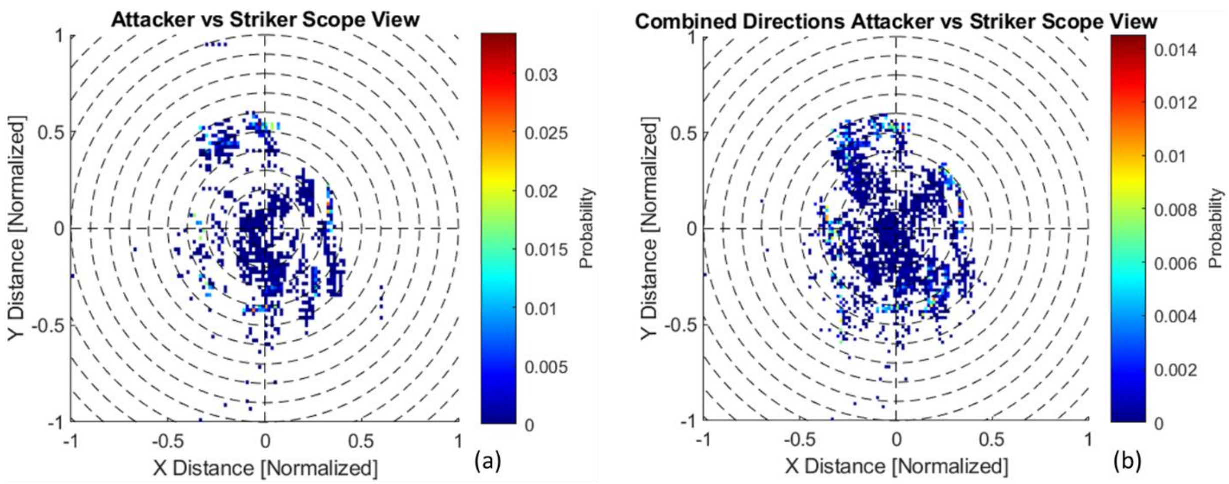

Figure 19: Comparative scope views of (a) 4 directions to (b) 8 directions

Much like the increase in information in the PDF of Figure 18, the scope views of Figure 19 are also fuller. The normalized distances here are again, very similar to each other. Figure 19.a. is of the original 4 cardinal directions with 19.b. being the combined 8 directions. The open spots existing within the circle of radius 0.4 in Figure 19.a. are filled in with Figure 19.b. Also, the highest probability demonstrated in Figure 19.a. is near 0.03 whereas in Figure 19.b. it is near 0.014. That is a little over a half reduction in probabilities. An explanation of this can be shown through looking at the points surrounding the western direction at a radius of 0.3 to 0.4. This information in Figure 19.a. is very dense and not surrounded by areas of lower probabilities. In

Figure 19.b, with the increase in the level of information, the same area has hotspots but is surrounded by areas of lower probability. This can give an analyst an increased level of confidence in the location and intensity of the hotspot, similar to the PDF earlier. Using the information from the 8 directions combined, the areas of high probability have begun to be surrounded by areas of lower probability.

5. Conclusions & Future Work

The definition of risk for a scenario within a wargame is highly subjective. A methodology was proposed that given adequate positional data, an analyst, given the right tools, could ascertain the points of interest in both the distance and directional sub-components. This is contingent upon adequate variations in initial conditions as well as convergence of the desired parameter to a level that allows for this to occur. It was shown that the tools of an absolute positional plot, probability density function, and scope view are capable of displaying and correlating these values across each other. The analyses that come from these plots can be modified by changing sources and end points and can be in relation to stationary and transitive units. Units can be separated and compared based on their abilities to interact and conclusions correlated with each other. An analyst has many decisions to make while using these plots.

Future testing is needed in the variations of the initial conditions that are required to adequately confirm that the data retrieved is enough to perform a reasonable analysis. A study should be performed similarly like the North Study and hotspots analyzed similar to how they are done when comparing 4 directions versus 8 directions. A different approach to potentially take in this endeavor to verify that enough directions have been utilized would be to set a level of convergence of the PDF and iterating through 4, 8, 16, and etc. directions until the plot changes less than the desired value.

Further, the results drawn by the author on the reasonableness of plots should be compared with those of an individual whose job it would be to use the outputs of these plots to make decisions. Due to the nature of AFSIM, a verification model does not exist and would be difficult to create since it is a system of systems. However, a methodology needs proposed that would allow for users to verify methods against known results. This, like most validation models, would increase the confidence in the plots designed and that their conclusions to be drawn are reasonable. Also, a method of quantifying and displaying the state-space of the simulation is required to fully fill out the desired methodology, as displayed in Equation 1. The combination of positional data as well as state data that explains the past and future actionable events that can be taken by a unit would allow an analyst to have a complete picture on the risk of a total simulation.

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