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STREAMLINED MODEL COMPOSITION FOR ONESAF FOR USE IN RAPID TRADE STUDY DATA COLLECTION AND ANALYSIS

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ABSTRACT

This research is meant to enhance the analytic capabilities of OneSAF for usage as a Monte Carlo-style data generator for use in large problem space trade studies. Using novel ground vehicle data such as: RHA armor values, weapon penetration prediction models, and sensor values, new models can be developed in OneSAF for use in data generation and analysis. This process and companion software developed for this purpose enables the rapid construction and evaluation of differing vehicle variants in a fraction of the time of the baseline process, improving the efficiency of using OneSAF as a data analysis tool. This approach facilitates a more comprehensive virtual experimentation approach that can use manufactured data as a part of the process.

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1. INTRODUCTION

The One Semi-Automated Forces (OneSAF) is a constructive simulation tool with a variety of use cases. One such feature is the capability to repeatedly operate a scenario in faster-than-real-time execution, which allows for data generation, collection, and analysis of many runs of one or multiple scenarios. This research is meant to enhance the analytic capabilities of OneSAF for usage as a data generator for GVSC-IS Virtual Experiments and trade study analysis. Using novel ground vehicle data such as RHA armor values, kinematic weapon penetration prediction models, and nominal sensor capabilities, a model can be generated in OneSAF that accurately reflects the capabilities of the data source, whether a real or theoretical vehicle. The Streamlined Vehicle Composer (SVC) is a tool that was developed as a part of the process of translating experimentation data to OneSAF. Its role was to fulfill a need for capable translation of bulk datasets into functional OneSAF models, enabling the rapid construction and evaluation of differing vehicle variants in a fraction of the time of the baseline process. The SVC was developed to help automate part of the process that traditionally takes days or weeks of manual configuration, reducing it to hours of automated composition. The approach documented below further facilitates a more comprehensive virtual experimentation approach that can use any potential data source as a part of the model development process, allowing for the construction of OneSAF models via a Digital Engineering, data-based approach.

2. MOTIVATION

2.1. Model Development

The shift towards digital engineering-based efforts is accelerating system design and the adoption of emerging technologies, creating a growing need for tools that streamline the entity development process within constructive simulation tools such as OneSAF. The SVC was developed to address this need by enabling faster and parallel creation of simulation-ready entities. OneSAF as a software, as a tool, and as a data generation utility is only as good as the models that are used with it. It was determined to be an operational necessity to translate the "real-world" unit configurations of Virtual Experiment vehicles to the OneSAF models to ensure accurate data for analysis. Due to the differences that existed between the methods of constructing the models within OneSAF versus external to OneSAF, such as in a Virtual Experimentation toolkit, it was deemed necessary to create a translation tool that could take data represented in different ways and put them directly into the form expected by the OneSAF engine. This required the ability to translate multiple forms of data into the OneSAF expected format. A convenient feature of exploring this avenue of data-translation was the development of a system to translate complete models in bulk to account for a large potential state-space of vehicle configurations. It also allowed for a quick automated method to rapidly emplace the vehicles into identical scenarios for direct A-B testing between different variants in the same operation.

2.2. Vehicle Data Translation

In practice, datasets are seldom homogeneous or comprehensive. They're typically heterogeneous, incomplete and contain inconsistencies, which presents a significant challenge for direct integration into simulation models. This is especially true when the data is gathered from a variety of sources which increases the potential for gaps, discrepancies, and other flaws. The SVC as the translation layer attempts to take data from different sources and accurately consolidate it into a form palatable for OneSAF. This is done by conducting the common operations regarding the effectiveness of armor, munitions, and sensors into a consistent set of operations that account for the different methods used to record and track such statistics. Once the model has been imported into OneSAF, it takes the form of a complete entity model in an extension added to OneSAF's core model base. Since the new model is also constructed in the same form as OneSAF's other models, the process of collecting data is the same as any core OneSAF model allowing for consistent processes to be used with models created through processes internal or external to OneSAF itself.

3. DIRECT FIRE MODEL DEVELOPMENT

3.1. Introduction of Methodology

Part of our development for this effort consisted of looking into how OneSAF operates as a simulation and comparing it to how data is collected and recorded in real-world scenarios or simulations. The different methodologies that we found relevant to our program are listed in detail below along with the methods we developed to bridge the data gap from our collection sources to OneSAF's internal system.

3.2. Deriving the Probability of Hit

To derive a function calculating the probability of hitting a target, we made the following basic assumptions. Given a tank gun with a specified dispersion angle θ_{Dsp}, and a Gaussian distribution of projectile trajectories, we assumed that 95% of projectiles would fall within the given dispersion angle, and thus, it would correspond to 4 standard deviations σ of a basic Gaussian distribution: thus, $\theta_{Dsp} = 4\sigma$. Since tank crews are trained to always aim at the center of mass of a target, to maximize the probability of a hit, the mean offset of the Gaussian μ is set to 0, to simplify calculations. Thus, the basic probability curve for a given tank gun is defined by the standard Gaussian probability function, where $\sigma = \theta_{Dsp}/4$. This basic case is illustrated in the figure below.

$$p(\theta) = \frac{1}{\sqrt{2\pi}\sigma} e^{-\left(\frac{\theta^2}{2\sigma^2}\right)}$$

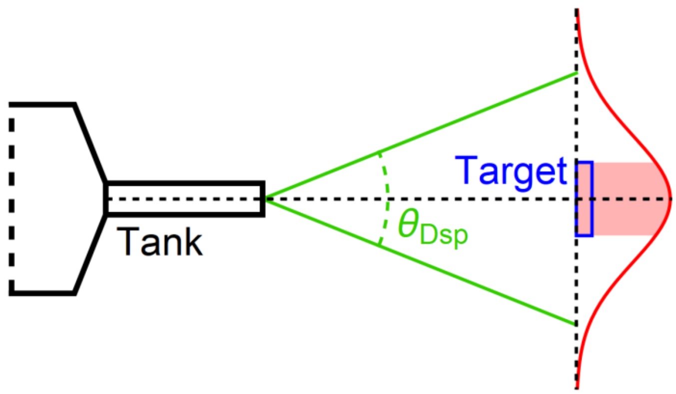

Figure 1: Conceptual Illustration of the Dispersion Pattern

The univariate Gaussian on its own, however, is not sufficient to describe the probability of hitting a target, because the projectile can miss the target in azimuth, as well as in elevation. Thus, we need to use the bivariate Gaussian distribution $p(\theta_x, \theta_y)$, with one variable (θ_x) describing the azimuth, and the second variable (θ_y) describing the elevation of a specific projectile's trajectory. As before, we assume that the tank gun is aiming for the center of mass of a given target, so both mean offsets μ_x and μ_y are simplified to 0. Since the gun is cylindrically symmetric, both standard deviations σ_x and σ_y are assumed to be identical, and are thus simplified to one common variable σ, for ease of computation. The correlation factor ρ of the bivariate Gaussian is also simplified to 0 in this analysis, for the same reason.

$$p(\theta_x, \theta_y) = \frac{1}{(2\pi\sigma^2)} e^{-\frac{1}{2}*\left(\frac{\theta_x^2+\theta_y^2}{\sigma^2}\right)}$$

Having selected our basic mathematical model, we can implement variables that correspond to the distance from the tank gun to the target d_{Tar}, the width of the target w_{Tar}, and of course the tank gun's dispersion angle θ_{Dsp}. For this initial analysis, we assume that the target is facing our tank gun head on, and thus only the front side of it is visible, which is perpendicular to the axis of the tank gun. Since our gun is aiming at the center of mass of the target, we can calculate the angular size θ_{Tar} of the target (from the perspective of the gun) as:

$$\theta_{Tar} = 2 * \operatorname{atan}\left(\left(\frac{w_{Tar}}{2}\right)/d_{Tar}\right)$$

The net probability of hitting the target P_{Hit} is calculated as a double integral of our bivariate Gaussian distribution. For the initial calculation, we assume that the target is square, with both its width and its height equal to w_{Tar}. Since we are integrating a Gaussian expression, the result will be an expression defined by the Gauss Error Function

$$P_{Hit}(d_{Tar}) = \int_{\theta_y=-\frac{\theta_{Tar}}{2}}^{\frac{\theta_{Tar}}{2}} \int_{\theta_x=-\frac{\theta_{Tar}}{2}}^{\frac{\theta_{Tar}}{2}} \left(\frac{1}{(2\pi\sigma^2)} e^{-\frac{1}{2}*\left(\frac{\theta_x^2+\theta_y^2}{\sigma^2}\right)}\right) * d\theta_x * d\theta_y$$

$$P_{Hit}(d_{Tar}) = \left(\operatorname{Erf}\left[\frac{2\sqrt{2}}{\theta_{Dsp}} \operatorname{atan}\left(\frac{\left(\frac{w_{Tar}}{2}\right)}{d_{Tar}}\right)\right]\right)^2$$

In this calculation, we assumed a square target, and therefore, the probability P_{Hit} given the bivariate Gaussian distribution is simply the square of the result if it were calculated for the univariate Gaussian distribution. This allows us to compare the two probabilities, and examine the significance of the bivariate Gaussian. For this example, we will assume a dispersion angle $\theta_{Dsp} = 0.05\ [deg]$ and a square target with width $w_{Tar} = 5\ [m]$. In the plot below, the univariate Gaussian is plotted in red and the bivariate Gaussian in blue. The plot shows a strong divergence of the two probabilities once the target is at a distance where an accurate hit is no longer guaranteed, and thus demonstrates the inflated probability of hit that would have been calculated if we only used the univariate Gaussian alone.

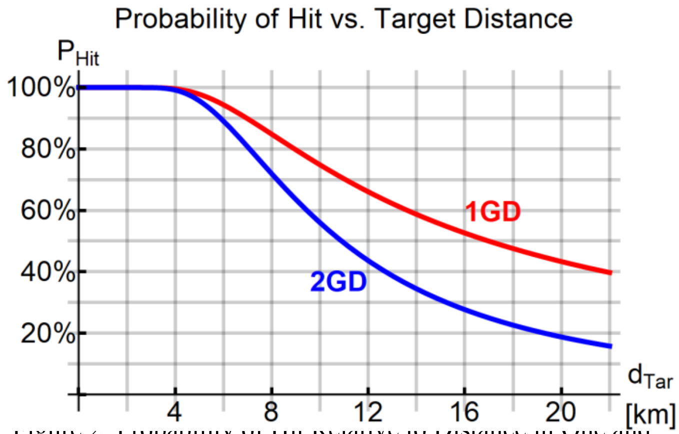

Figure 2: Probability of Hit Relative to Distance in One and Two Gaussian Distributions

Since real world targets are rarely true squares, we will need to incorporate both the width w_{Tar} and the height h_{Tar} of the target into our expression, expanding the total expression of probability of hit to:

$$P_{Hit}(d_{Tar}) = \mathrm{Erf}\left[\frac{2\sqrt{2}}{\theta_{Dsp}}\mathrm{atan}\left(\frac{\left(\frac{w_{Tar}}{2}\right)}{d_{Tar}}\right)\right] * \mathrm{Erf}\left[\frac{2\sqrt{2}}{\theta_{Dsp}}\mathrm{atan}\left(\frac{\left(\frac{h_{Tar}}{2}\right)}{d_{Tar}}\right)\right]$$

The analysis thus far had addressed a target whose front surface is directly oriented towards the tank gun. In reality, however, any given target will have multiple faces that are seen at some angle of obliquity ϕ with respect to the axis of the tank gun, as illustrated. In the selected formulation, at an angle $\phi = 0°$ the target is seen directly head on, with its front surface visible, and at $\phi = 90°$ the target is seen edge on, with its side visible.

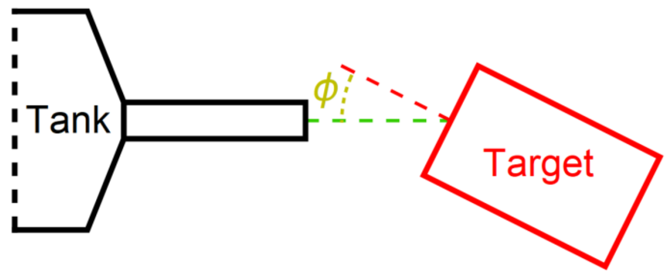

Figure 3: Angle of Target Relative to Tank Gun

We thus need to add a new variable, defining the length of the target l_{Tar}, to remain consistent with our prior calculations involving the width w_{Tar} and height h_{Tar}. We will assume that our tank gun and the target are far enough away from each other for perspective distortion to not be relevant, and that both the tank and the target are at equal elevation on a flat plane, so that the target does not expose its upper or lower surface, and its height axis always remains perpendicular to the flat plane, with no terrain based sloping between our tank gun and the target. In this scenario, the line of sight width of the target can be computed as $w_{Los} = w_{Tar} * \cos(\phi)$ and its line of sight length as $l_{Los} = l_{Tar} * \sin(\phi)$. To calculate the total probability of hit, we need to account for the complete line of sight breadth of the target, which is equal to $w_{Los} + l_{Los}$, and incorporate that into the P_{Hit} function.

$$P_{Hit} = \mathrm{Erf}\left[\frac{2\sqrt{2}}{\theta_{Dsp}}\mathrm{atan}\left(\frac{\left(\frac{w_{Tar} * \cos(\phi) + l_{Tar} * \sin(\phi)}{2}\right)}{d_{Tar}}\right)\right] * \mathrm{Erf}\left[\frac{2\sqrt{2}}{\theta_{Dsp}}\mathrm{atan}\left(\frac{\left(\frac{h_{Tar}}{2}\right)}{d_{Tar}}\right)\right]$$

For a target vehicle with width $w_{Tar} = 3\ [m]$, length $l_{Tar} = 6\ [m]$, and height $h_{Tar} = 3\ [m]$, and a gun dispersion angle $\theta_{Dsp} = 0.08333°$, we calculate the following distance dependent probability of hit plots, given a target angle of obliquity ϕ ranging from 0° to 90° in 30° increments. As anticipated, the probability of hit is lowest when the target is facing directly head on, with $\phi = 0°$, and increases noticeably when the target is at a nonzero oblique angle. The probability of hit drops slightly when the target is viewed from the side, with $\phi = 90°$, since then the front surface is completely hidden from view in that condition.

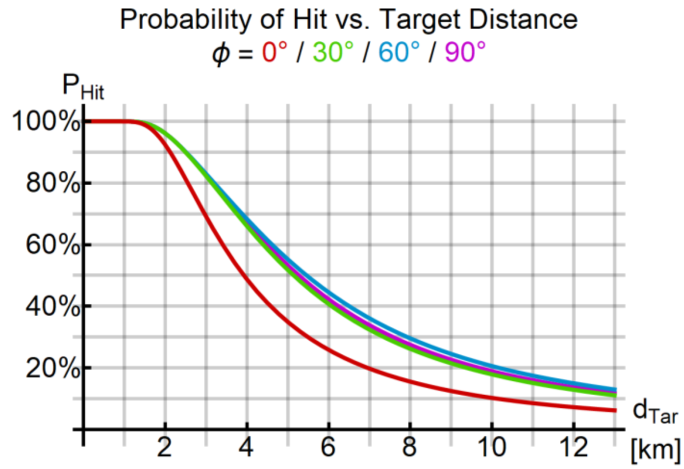

Figure 4 : Probability of Hit at Distance Accounting for Vehicle Rotation Angle

3.3. Deriving the Probability of Penetration

In deriving the fundamental function calculating the probability of penetration, we likewise have to make a set of basic assumptions, described in this section. We start with an idealized armor piercing projectile, with a nominal expected depth of penetration d_{RHA} into RHA (Rolled Homogeneous Armor) – the standard measure of comparison for effective armor thickness and armor penetration. Due to inevitable inconsistencies in the production quality of both projectiles and armor plates, we expect a probability distribution of actually achieved armor penetration, given a population of nominally identical projectiles and plates. This distribution we choose to model as a univariate Gaussian distribution, describing the achieved armor penetration depth d_{pen} of a given projectile against a given armor plate in the population, to simplify our calculations. The Gaussian mean μ here would correspond to the expected armor penetration depth d_{RHA} of the projectiles, and the standard deviation σ would determine the uncertainty of achieved armor penetration across the population. This uncertainty we model by multiplying a small coefficient k_{unc} by the expected armor penetration depth: $\sigma = k_{unc} * d_{RHA}$

$$p(d_{pen}) = \frac{1}{\sqrt{2\pi}\sigma} e^{-\left(\frac{(d_{pen}-\mu)^2}{2\sigma^2}\right)}$$
$$= \frac{1}{\sqrt{2\pi} * (k_{unc} * d_{RHA})} e^{-\left(\frac{(d_{pen}-d_{RHA})^2}{2(k_{unc}*d_{RHA})^2}\right)}$$

Using this Gaussian distribution, we can calculate the cumulative probability P_{succ} that a given projectile in the population can successfully penetrate an armor plate of arbitrary thickness th_{arm}. This can be found as the integral of the Gaussian from 0 to th_{arm}, subtracted from 1, since the probability of penetrating an exceptionally thin plate will be 100%

$$P_{succ}(th_{arm}) = 1 - \int_0^{th_{arm}} p(d_{pen})$$
$$= 1 - \frac{1}{2}\left(\mathrm{Erf}\left[\frac{th_{arm} - d_{RHA}}{\sqrt{2} * k_{unc} * d_{RHA}}\right] + \mathrm{Erf}\left[\frac{1}{\sqrt{2} * k_{unc}}\right]\right)$$

The function above is plotted out in the figure below for the specific case of $d_{RHA} = 800\ [mm]$ and $k_{unc} = 0.10$. As can be seen from the plot, in the given formulation, the probability of penetrating a plate of equal thickness to the expected depth of penetration d_{RHA} is exactly equal to 50%, with a smooth cumulative Gaussian curve centered around that point.

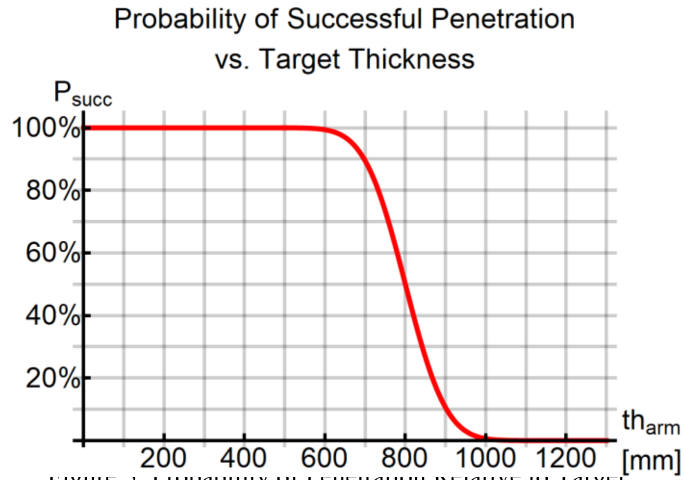

Figure 5: Probability of Penetration Relative to Target Armor Thickness

The analysis above is relevant to armor penetration into a plate which is itself perpendicular to the direction of motion of the incoming projectile. In the vast majority of cases, however, the projectile will come in at some angle of obliquity with respect to the armor plate. Thus, we need to also account for the line-of-sight thickness of an armor plate, at a given angle of obliquity ϕ, using the same definition for this angle as in the preceding section.

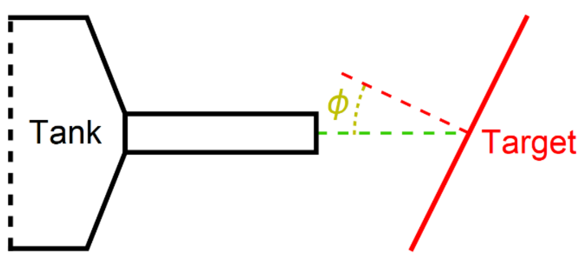

Figure 6: Angle of Target Relative to Tank Gun

While much more detailed analysis is available from a variety of historic studies on armor penetration, such as the work of Jacob de Marre, examining the penetration of sloped armor plates, for the purpose of this simple analysis, we will use a straightforward line of sight thickness, calculated as $th_{Los} = th_{arm}/\cos(\phi)$. This thickness will be directly incorporated into the cumulative probability of penetration function, giving its final form for a single plate:

$$P_{succ}(th_{arm},\phi) = 1 - \frac{1}{2}\left(\mathrm{Erf}\left[\frac{\frac{th_{arm}}{\cos(\phi)} - d_{RHA}}{\sqrt{2} * k_{unc} * d_{RHA}}\right] + \mathrm{Erf}\left[\frac{1}{\sqrt{2} * k_{unc}}\right]\right)$$

Now, we can use the above formulation to compute the total probability of penetration against a target vehicle, with a front surface and a side surface, situated at an angle of obliquity ϕ. We remind the reader that at angle $\phi = 0°$ the target is seen directly head on, with its front surface visible, and at $\phi = 90°$ the target is seen edge on, with its side visible, as defined earlier. Since most combat vehicles have different armor protection for their front and their sides, we introduce two new variables: armor thickness along the front th_{fr} and armor thickness along the side th_{sd}. Correspondingly, there are also now two separate probabilities of a successful penetration, $P_{succ,fr}$ and $P_{succ,sd}$, since we are treating the two surfaces as separate entities. Note that in $P_{succ,fr}$, th_{fr} is divided by $\cos(\phi)$ to calculate the line of sight thickness, as was described earlier, but in $P_{succ,sd}$, th_{sd} is divided by $\sin(\phi)$, since the side wall is perpendicular to the front surface of the target vehicle.

$$P_{succ,fr} = 1 - \frac{1}{2}\left(\mathrm{Erf}\left[\frac{\frac{th_{fr}}{\cos(\phi)} - d_{RHA}}{\sqrt{2} * k_{unc} * d_{RHA}}\right] + \mathrm{Erf}\left[\frac{1}{\sqrt{2} * k_{unc}}\right]\right)$$

$$P_{succ,sd} = 1 - \frac{1}{2}\left(\mathrm{Erf}\left[\frac{\frac{th_{sd}}{\sin(\phi)} - d_{RHA}}{\sqrt{2} * k_{unc} * d_{RHA}}\right] + \mathrm{Erf}\left[\frac{1}{\sqrt{2} * k_{unc}}\right]\right)$$

Finally, we can combine the expressions for separate penetration probabilities with the expressions computing the line of sight width w_{LoS} and length l_{LoS}. Due to the length of the full expression, the term in the numerator is presented as a column of distinct functions multiplied and added together.

$$P_{succ} = \frac{P_{succ,fr} * w_{LoS} + P_{succ,sd} * l_{LoS}}{w_{LoS} + l_{LoS}} =$$

$$= \frac{\begin{array}{c}\left(1 - \frac{1}{2}\left(\mathrm{Erf}\left[\frac{\frac{th_{fr}}{\cos(\phi)} - d_{RHA}}{\sqrt{2} * k_{unc} * d_{RHA}}\right] + \mathrm{Erf}\left[\frac{1}{\sqrt{2} * k_{unc}}\right]\right)\right) \\ * \\ (w_{Tar} * \cos(\phi)) \\ + \\ \left(\begin{array}{c}\left(1 - \frac{1}{2}\left(\mathrm{Erf}\left[\frac{\frac{th_{sd}}{\sin(\phi)} - d_{RHA}}{\sqrt{2} * k_{unc} * d_{RHA}}\right] + \mathrm{Erf}\left[\frac{1}{\sqrt{2} * k_{unc}}\right]\right)\right) \\ * \\ (l_{Tar} * \sin(\phi))\end{array}\right)\end{array}}{w_{Tar} * \cos(\phi) + l_{Tar} * \sin(\phi)}$$

Using this combined function, we can plot out the full probability of penetration against a target vehicle given any arbitrary angle ϕ. In the example computed here, we use a target vehicle with width $w_{Tar} = 3\ [m]$, length $l_{Tar} = 6\ [m]$, frontal armor $th_{fr} = 800\ [mm]$, and side armor $th_{sd} = 200\ [mm]$, being shot by a projectile with nominal penetration depth $d_{RHA} = 800\ [mm]$, and penetration uncertainty $k_{unc} = 0.10$. Since the resultant plot is very complex, we will build it up step by step, to provide intuition.

In the first plot presented below, we independently plot out four separate lines. Red lines describe the front armor plate, while blue lines describe the side armor plate. Dotted lines represent the view fractions of the plates from the perspective of the gun. When $\phi = 0°$ and the front surface is facing the gun, it has 100% of the view fraction, while the side surface has 100% of the view fraction when $\phi = 90°$ and the target is seen from the side. Dashed lines represent the probability of penetrating the front and side plates, given the target vehicle's angle of obliquity ϕ. As expected, the front plate starts with 50% probability when viewed directly head on, and as ϕ increases, the probability of penetration reduces. Conversely, the side plate starts at 0% probability of penetration, since it is effectively parallel to the gun at $\phi = 0°$, and thus has theoretically infinite line of sight thickness, but already at a small angle of obliquity, the plate is easily penetrated, and for most of the range of ϕ the probability of penetration is 100%.

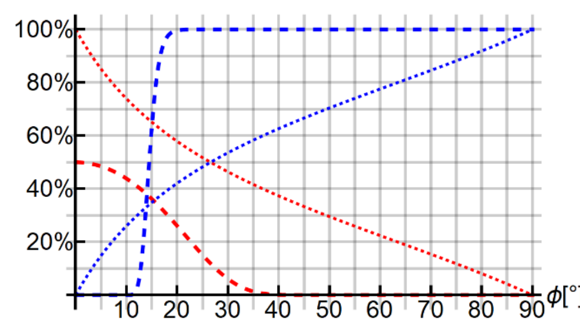

Figure 7: View Fraction and Probability of Penetration for Front and Side Armor

In the next plot, we multiply the respective view fractions by the probabilities of penetration, with the results represented by the newly introduced solid lines. Each solid line represents the total probability of both hitting and penetrating the respective armor plates, individually. Most notable is the behavior of the blue line, representing the weak side armor. Even though the probability of penetration alone is 100% for most of the range of angles ϕ investigated, the probability of hit and penetration does not reach 100% until $\phi = 90°$ and the target is viewed directly from the side. At lower angles of obliquity, the presence of the front plate within the field of view maintains a decreasing but nonzero probability that the projectile will hit that front plate instead and fail to penetrate the target vehicle.

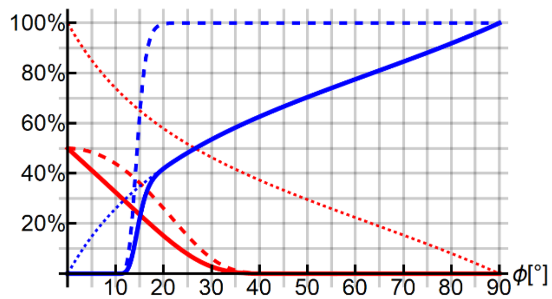

Figure 8: Probability of Penetration Weighted by View Fraction

Finally, we produce the combined plot, represented by the purple line, describing the net total probability P_{succ} of successfully penetrating the target vehicle as a function of the angle ϕ, taking into account the thicknesses of the front and side armor plates, and their respective dimensions. This total probability of successful penetration is the <u>sum</u> of the solid blue and red lines observed in the preceding figure. At small angles ϕ the probability is dominated by the front plate (red line above), while at large angles ϕ the probability is dominated by the side plate. Probability of penetration for intermediate angles, where both the side and front plates have nonzero magnitude, shows some very interesting behavior, the specific shape of which is determined by the respective thicknesses and dimensions of the two plates.

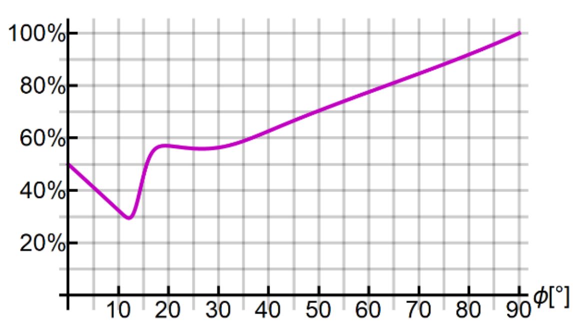

Figure 9: Probability of Successful Penetration

3.4. OneSAF Damage Assessment

With the formulae established, we can make these calculations for every vehicle and munition combination produced through the SVC. By calculating the probability and expected depth of penetration, we can correlate kinematic ballistic data calculations to values that OneSAF would expect of its models. These values are then used by the simulation to determine the damage dealt during firing events. Depending on the severity, it can have adverse effects on the performance or complete destruction of the target vehicle. Our calculation of probability of penetration versus target thickness shown in Figure 5 shows a small band of armor thickness that would result in a non-deterministic result, whereas an over-armored or over-gunned conditions have nearly guaranteed results. OneSAF's models correlate in a similar fashion where an over-armored or over-gunned model will have nearly guaranteed results, but a more equivalent match-up will have less consistent results. The calculated probability of penetration translates directly to the model's vulnerability using similar factors that make for an easy transition from one simulation to another. Thus, the SVC automatically executes the process of making these calculations as a part of assembling the model for use in OneSAF based on the data provided to it.

4. VEHICLE DATA

4.1. Custom Entity Types

OneSAF builds its vehicles up from a core structure called an entity type. The entity type defines the very basic aspects of a vehicle, things like wheels versus tracks for example. It also defines many of the default values used in an entity for things like weight, horsepower, and other aspects. According to Longsdon [1], a core feature of OneSAF's development philosophy is composition, the idea of taking existing pieces and rearranging them into new constructs. To that philosophy, the entity type and subcomponents define the remaining pieces required of a complete vehicle and are built on top of the core entity type. In our specific use-case we found a need for different unique entity types that were not available in the OneSAF base, this led to the SVC developing the ability to compose new entity types to better fit the data that we were adapting from. This allowed us a means to develop novel vehicles that were built in the same fashion as all OneSAF entities without sharing the same data elements as many of the core vehicles.

4.2. Custom Weapon Components

In the same vein, weapons are constructed in a similar way. There is a baseline model that is built upon to construct each specific type and the need for special layouts was also needed. Unlike vehicles, the data required to make a custom weapon are more disparate and scattered across many files. The SVC was developed to handle this use case to improve efficiency in the development process, automatically traversing the file structure and populating the data tables with the translations of the input data.

4.3. MOA to Mils

One such translation that the SVC performs is from Minute of Angle (MOA) to Milliradians (Mils). OneSAF uses milliradians (Mils) as its standard unit for accuracy in its data files. Our data sources often recorded this data in MOA. The SVC does this using the standard formula as described by Simeone [2], a simple linear conversion by a factor of 3.438 between Mils and MOA. It is a simple translation, but it is critical to maintain a consistent result across OneSAF and other experimentation sources. This translation is also critical to the other process the SVC performs which is the calculation of the weapon accuracy data for the novel weapons that we composed.

4.4. Weapon Accuracy

OneSAF uses Mils as a part of the process it uses to bake accuracy in a model's physical components. The weapon physical component holds a series of data points that the simulation uses to calculate the potential spread of a shot during a firing event. We found that manipulating these variables is critical to getting weapons to act more according to data from external sources. The SVC uses MOA data from external sources and calculates the Mils expected by OneSAF and applies them to the weapon model to align the weapon's accuracy with what was seen from other sources.

5. RESULTS AND EXECUTION

5.1. SVC Execution

In this section we will detail how the SVC tool takes the data from the user and inputs that data into OneSAF to create vehicles, entity types, weapons, munitions and other components into functional OneSAF models. The composition process takes the data from VE's and the baseline composition components of OneSAF to produce a complete entity. As a result of the cross between data and OneSAF components, the SVC composes entity types, weapons, and munitions. Those components are then used to compose a vehicle entity. The SVC will take all the components and vehicles developed by the user and input them in the appropriate corresponding spreadsheets and data files in a custom OneSAF extension to create functioning OneSAF vehicles, weapons, and munitions.

The SVC will create the new extension for OneSAF and put all of its vehicles, components, and data into this new extension, following the methods used by OneSAF for compartmentalization. This also includes specific data spreadsheets, that when OneSAF is rebuilt are conglomerated with each equivalent in the base software and other extensions to form the collective of models used in the simulations. By creating this new extension and inputting all new data and models into the extension ensures a separation from the baseline OneSAF models and anything new that is generated by the SVC. This arrangement is also in-line with the OneSAF development process thus it uses the core extension system to add the new components and entities into the program.

5.2. Base Vehicle Type

The SVC is capable of creating three different types of vehicles including Infantry Fighting Vehicles (IFV), tanks, and Unmanned Aircraft Systems (UAS), and more specifically quadcopters. When creating a new vehicle or entity type, the user will need to select a base vehicle type. The base vehicle type is used by the SVC to define the basic characteristics of the vehicle that the user is trying to create. The majority of the attributes in the base vehicle are not data points or physics attributes. These values include the vehicles functional area, chassis type, target mapping abbreviation, and platform type. OneSAF has multiple unique characterizations and terminology used to define different aspects of a vehicle or entity type. The base vehicle types in the SVC will set these OneSAF specific values. All vehicles that share the same base type will share all the attributes of that base vehicle type. These are not necessarily used by the end user, but more by OneSAF in the background, the SVC is designed to match OneSAF standards without the user knowing all the ins and outs of OneSAF specific characterization and terminology to input their vehicle data.

5.3. Entity Types

To create a new entity type in OneSAF using the SVC the user must input a valid entity type name for the entity to be identified as by OneSAF, select a base vehicle type, enter the mass, engine horsepower, max speed, hull dimensions, hull armor values, select if the entity type has Explosive Reactive Armor (ERA), if the entity type has Active Protection Systems (APS), if the entity type has a main turret, the turret dimensions, turret armor values, and power source. If the entity type does not have a main turret, then the user will not need to input the turret dimension and armor values. The dimensions for the hull and turret will each set the length, width, and height of the simplified rectangular vehicle shape. The armor values consist of six RHA values for each hull and turret section of armor. Each section of armor will have values for the front, rear, and sides. The two individual sides will be simplified to the same values for each side. The front, rear, and side will each have two RHA values for the armor effectiveness again Kinetic Energy (KE) and Sharped Charge (SC) munitions. Making the six SVC armor values Front KE, Front SC, Rear KE, Rear SC, Side KE, and Side SC. The power source can either be set to fuel or electric. If the power source is set to fuel, the user will then need to enter the fuel type and fuel capacity of the entity type. If the power source is set to electric the user will then need to set the idle power consumption and the moving power consumption. The ERA and APS are used for extremely simplified SVC ERA and APS systems that only require the entity type and vehicle to specify if ERA and APS are equipped or not. This ERA and APS system will be described in more detail in a later section.

To create a new entity type the SVC will define the new entity type in OneSAF. Each entity type is defined with a unique entity type name to identify it within OneSAF spreadsheets, data files, and vehicle compositions. Entity types inherit the properties from the base vehicle type and add additional properties that are based more on physical attributes of the vehicle. The SVC will directly input the mass, engine horsepower, max speed, hull dimensions, and turret dimensions into the new entity type definition along with the values from the base vehicle type. The entity type will then be recognized and can be used in other OneSAF spreadsheet, data files, and vehicle composition XML files.

The entity type's dimensions, armor values, ERA, and APS data will be used to calculate the entity type probability of kill data. The probability of kill data is calculated using the probability of penetration formula described in a previous section for every weapon and munition compatible with each other being used against this entity type.

5.4. Weapons

In order to create a new weapon in OneSAF using the SVC, the user must input a valid weapon name, weapon mount type, minimum and maximum effective range, category rounds per shot (burst size), time between shots, barrel length, and barrel diameter. The user will also set all compatible munitions for this weapon and the performance data of the weapon and munition used together referred to as weapon munition values. To create a new weapon in OneSAF, the SVC will create a new weapon type and weapon composition XML file. The SVC will define the new weapon type in OneSAF to establish the weapon type name as a valid weapon type. The weapon type will then be recognized and can be used in other OneSAF spreadsheets, data files, and weapon composition files. The SVC will then create a weapon composition XML file using the newly created weapon type. The weapon composition will create the actual weapon component that will be used on vehicles. The weapon composition holds the weapon components burst size, minimum and maximum range, and mount type data that was inputted by the user in the SVC. All other data for the weapon will be used in calculating the performance and capabilities when used with a specific munition in different spreadsheets and data files.

5.5. Munitions

In order to create a new munition in OneSAF using the SVC, the user must input a valid munition name .for the munition to be identified as within OneSAF, munition category, minimum and maximum effective range, Explosive Reactive Armor (ERA) reduction percentage, Active Protective Armor (APS) reduction percentage, quantity per container, size of container, and mass of container into the SVC. The ERA and APS reduction percentages are used for a very simplified ERA and APS system used when the SVC calculates the probability of penetration. This simplified method will take the munition effective penetration RHA value and if the target vehicle has ERA or APS, the effective penetration value is reduced by the ERA and APS reduction percentage as it is affected by the ERA and APS systems. Depending on each individual munition's characteristics the munition could be completely defeated by ERA or APS or not affected at all, this is reflected in this simplified ERA APS system. The user will also set all compatible weapons for this munition and the performance data of the weapon and munition used together referred to as weapon munition values.

To create a new munition in OneSAF, the SVC will need to create a new munition type in OneSAF. The munition type will define some base characteristics of the munition but will not define the performance of the munition. The performance of the munition is defined when it is being used by a specific weapon. To create the new munition type, the SVC will take the munition type name, munition category, minimum and maximum effective range, quantity per container, size of container, and mass of container and directly input that data into the correct locations within OneSAF. The SVC will then set some default values depending on the munition type that the user would not typically know or need to know the OneSAF specific categorization of terminology used such as the unit of issue and warhead type.

5.6. Weapon-Munition Values

Every compatible weapon and munition component created by the SVC that will be used together will need additional data referred to as weapon munition values. Creating weapons and munitions by themselves do not create fully functional components they need to have data of how they perform when being used together. With the weapon munition values the SVC can then define the performance data for the weapons and munitions that are being used together. The weapon-munition values are derived from the entered data for the weapon and the munition to form a cohesive relationship between the two. The probability of kill data is calculated using the probability of penetration formula described previously.

5.7. Vehicles

To create a vehicle in OneSAF the SVC will create a vehicle composition XML file. The vehicle composition file is used to add all the pieces together to create a full functionating vehicle. The user will need to select a base vehicle type, entity type, crew, weapons, munitions, and sensors for the SVC to add to the vehicle composition to create the vehicle in OneSAF.

To create a vehicle composition file the SVC will start by creating a base vehicle composition file. The base vehicle composition is a stripped-down basic outline of a vehicle composition that has only the bare minimum information and structure to be a valid OneSAF composition file. Then based on the SVC base vehicle type selected, the SVC will add several standard OneSAF components that all vehicles of that base vehicle type will have. These components range from physical components like the vulnerability component to behavioral components like the ground vehicle driver component, all the pieces that need to come together to make a complete vehicle. These standard OneSAF components will give the vehicle the basic functionality that all vehicles of the selected base vehicle type have.

The SVC will use the selected entity type to add specific data from the entity type definition into the vehicle composition such as the mass and dimensions. The entity type will be explicitly set in the vehicle composition to enable the vehicle to inherit all the entity type armor data and other capabilities set for that entity type in OneSAF.

The SVC has a list of standard crew configurations that the user can add to the vehicle model being developed. For example, a four-person standard crew has a commander, driver, gunner, and loader. Each crew component is connected to the relevant physical and behavioral components for the basic operation of the model.

For every weapon added to the vehicle composition by the SVC, a new physical component will be added to the vehicle composition. The weapon physical component will also be added as an available component for the direct fire controller. This will enable crew members such as the gunner and loader to use the weapon. All munitions and supplies are added to the basic load of the vehicle composition. The same process is conducted for the other physical components that can be processed by the SVC like vehicle sensors.

5.8. Sample Trade Study Experiment

A test scenario was set up to simulate and demonstrate the potential for trade-space studies with OneSAF and SVC. The scenario is entirely built using SVC-constructed notional vehicle models, a OPFOR vehicle carrying a 125mm main gun with APFSDS rounds is positioned 2 km away from our test vehicles. The BLUFOR vehicles are simple tracked vehicles with a range of increasingly thicker armor packages. The armor configurations range from 600 mm to 800 mm of front armor, stepping by 50 mm, with half the front armor thickness on the sides and rear. Vehicle configuration 1 has an armor package of 600 mm on the front, 300 mm on the sides and rear and vehicle configuration 5 has 800 mm on the front, 400 mm on the sides and rear. The turret on each vehicle also shares this configuration. While this sample space is not necessarily realistic to real-world vehicle construction, it is meant to demonstrate the rapid construction of models of various types and styles.

In the combat scenario, the OPFOR vehicle fires on the BLUFOR vehicle until either a kill state is confirmed, or the simulation reaches the 1-hour time limit. The scenario is then repeated with the OPFOR vehicle having moved 15 degrees clockwise relative to the BLUFOR vehicle, to 180 degrees or behind the vehicle. This arrangement demonstrates the change in performance from the different sides of the various armor packages as well as at different angles, such as the 15 degree angle which is essentially still firing on the front armor with a slightly thicker effective armor. Our notional weapon, with an expected muzzle velocity of 180 m/s, the expected depth of penetration is approximately 700 mm. As discussed earlier, each firing event would have some amount of variance from the expected due to real-world factors. OneSAF's firing events apply a similar distribution, so the exact performance of the weapon varies similar to what would be expected in the real-world. As we will see in the data, the depth of penetration variance results in penetration depths less than 600 mm or greater than 800 mm.

The data collected regarding firing events and damage reports was then processed through a series of Python scripts to assess the effectiveness of each armor package. This allows us to gather basic results of survivability and armor package performance. Each arrangement of vehicle and armor orientation is repeated 100 times. In Figure 10, we can see the advantage that larger armor packages have relative to survival time. Specifically, vehicle configuration 5 has a significant improvement in survival time over the other configurations when hit on the front due to its front armor, 0 and 15 degrees, being consistently thicker than the average expected penetration depth. This advantage disappears as the scenario moves over to the side armor, where all the vehicle configurations feature armor weaker than the expected penetration depth, with any advantage had disappearing at the 45 degree angle, with no discernable difference for 60-180 degrees.

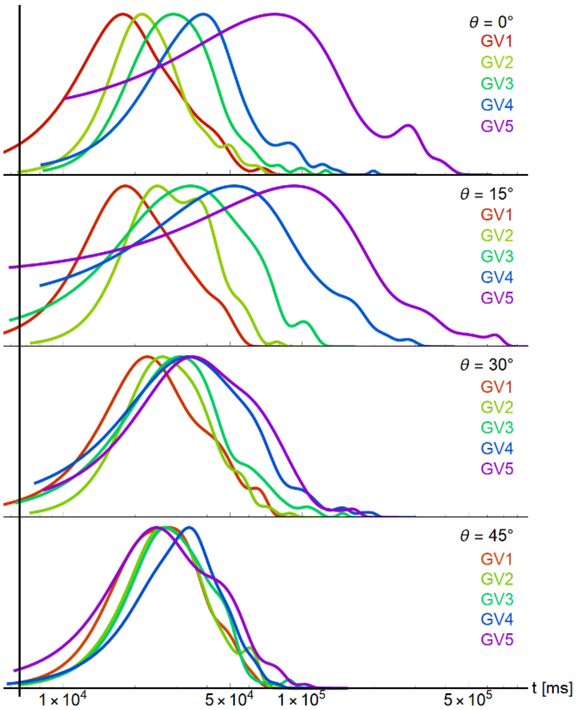

Figure 10: Time to Kill of each vehicle configuration at the 0 to 45 degree angles.

The relationship between this demonstrated advantage and our earlier calculated probability of penetration in Figure 9 can be shown with the median and mean time to kill of each configuration at each angle.

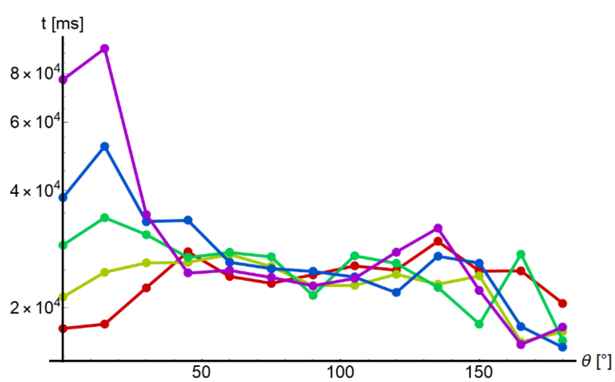

Figure 11: Median Time to Kill of each configuration at each angle.

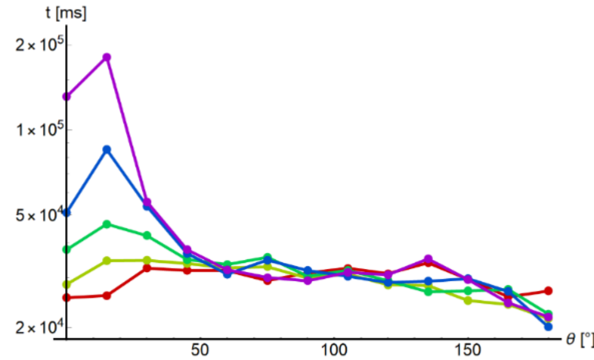

Figure 12: Mean time to Kill of each configuration at each angle.

What we see from these two graphs relative to Figure 9 is an inverted correlation, since a higher probability of kill will result in a lower time to kill on average. This includes the slight peak seen at the 15 degree angle where the time to kill rises slightly due to the effective thickness at an angle being thicker. If we were using these vehicle configurations in a mock trade study, we would then use the performances tracked as our metrics for comparing configurations. This test only checked the effectiveness of the armor packages, but similar tests could be conducted for weapons, sensors, and other systems within the capability of OneSAF to represent. This sample trade-space study is an example of the processes that the SVC enables by allowing the development of novel OneSAF models in a rapid fashion. The process of developing experiments with a large state space of vehicle configurations and testing each in a rapidly repeatable way allows for data collection and analysis at a much greater rate.

6. CONCLUSIONS

By developing additional tools like the SVC, OneSAF can be further enhanced to add capabilities for different usages. The SVC is an example of one such enhancement for data translation, Monte-Carlo style data generation, and with use as a trade study tool. The process described here is only one potential avenue of enhancement. Future work in this project could also produce an even more complete system. The SVC is limited to only a specific set of vehicle types; it is not capable of making every possible type of entity that could be used in OneSAF. This is an obvious avenue for future development. Similarly, the data ingested by the SVC is not all encompassing either, with different units, relevant calculations, and techniques of recording offering differences that the SVC is not currently set to handle. Other developments could include the capability to modify the subcomponents that come together to form OneSAF entities. The SVC does this for weapons and sensors, but that is a small pool relative to what OneSAF has to offer. While the tool as it exists now is a powerful alternative for model development, it still has potential to grow.

Using kinematics and probability, we found a potential avenue for taking real world data and translating it into a form that works for constructive simulations like OneSAF. Similar techniques are applicable to other simulations based on what is used to approximate reality. These abstractions are necessary for computing efficiency with large-scale simulations, but the data in use does not need to be compromised in the same way. Future developments can investigate further methods of translation, as improvements to the process can always be made.

7. REFERENCES

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10. ACRONYMS

ERA	Explosive Reactive Armor
GUI	Graphical User Interface
GVSC	Ground Vehicle System Center
OneSAF	One Semi-Automated Forces
IS	Immersive Simulation
RHA	Rolled Homogeneous Armor
SVC	Streamlined Vehicle Composer
Mils	Milliradians
MOA	Minute of Angle
OPFOR	Opposition Force
BLUFOR	Blue Force
APFSDS	Armor-Piercing Fin-Stabilized Discarding Sabot