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A Fidelity Framework for Small Arms Combat

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***Abstract*— The use of modelling and simulation (Mod-Sim) tools are becoming a crucial component in the design and evaluation of cyber and physical security systems. Many Mod-Sim tools exist for the elucidation of attack scenarios, characterization of facility vulnerabilities, and the construction and maintenance of optimal protection systems. The growing use of Mod-Sim tools for assessment of physical and cyber security systems necessitates a consistency in the existence of requirements and in the definitions of use for the models defined within a simulation.**

There currently exist many modelling and simulation (Mod-Sim) software tools available for use in characterizing various combat, physical, and cyber security scenarios. Even with the existence of a glossary distributed by MSIAC (Modeling and Simulation Information Analysis Center - U.S. Department of Defense) there is a lack of requirement specifications and definitions for many of the terms and processes used in the modelling and simulation field. A more meaningful understanding for the construction of useful analyses is needed. It is critical that requirements, definitions, and processes be clearly identified and agreed upon before undertaking any effort to establish an analysis tool. In so doing, more cost effective model and simulation tools can then be developed that will produce scenarios, environments, and execution models that provide more a meaningful analyses of interest.

In this paper, we will define the term fidelity and we will show how to consistently and appropriately apply the term to models that are used in simulation. Our intent is to bound the meaning so that it can be used as a definitive basis with which to assess how well a model, and its function within a scenario, satisfies the end goal of answering the appropriate questions for which the scenario and simulation were constructed.

Fidelity will be derived from various aspects of a model's purpose within a given simulation including the level of required interactivity amongst entities, the need to be realistic, and the complexity of the model. Many of the concepts from Object-Oriented programming have been leveraged to help identify required characteristics and interaction requirements of a core set of models that are deemed essential as a basis for all small arms combat scenarios. We will also demonstrate how our framework can be applied and extended to other cyber and physical security scenarios in an attempt to provide a fundamental construction methodology for all Mod-Sim efforts.

Index Terms*—*fidelity, modeling, simulation, physical security systems, cyber security systems, object oriented programming (key words)

I. Introduction

The fidelity of a simulation, as defined to be "the degree to which a model or simulation reproduces the state and behavior of its real world referent or an intended altered behavior and state of a real world referent (i.e. the intended realism of a model or simulation)", can be derived from two primary sources:

1. What are the essential elements (and their associated states) that are crucial in providing relevant insight into the behavior of a system or scenario?
2. How are the elements in item #1 defined, with respect to their associated behaviors and interactions, for a simulation such that they provide the required activity leading to accurate models of the targeted reality?

These two questions form the basis of our approach in providing a framework that can help to answer the question of: "What is the correct level of fidelity required to satisfy the intended purpose of a simulation.".

Our framework focuses primarily on the definition of an object's state (in item #1) and on the definition of an object's behaviors and interactions (all of item #2). To identify the essential elements necessary for an accurate simulation that meets an end-user's need is a design decision and process that lies outside the scope of this paper.

This framework focuses on identifying the level of fidelity associated with modeling and simulation tools whose scenarios are limited to small arms combat. Our intent is to present a framework that can be used in a fidelity assessment process for a modeling and simulation design as well as for the tools that will be employed to meet it. The fidelity framework assesses models, behaviors, and related connectivity in an attempt to standardize the definition, usage, and measurement of fidelity of a simulation with respect to a particular system or scenario. Through an application of this framework other efforts can be standardized as well, such as gap analysis, requirements generation, and identifying deficiencies in capability.

II. Fidelity Framework

A. Framework Composition

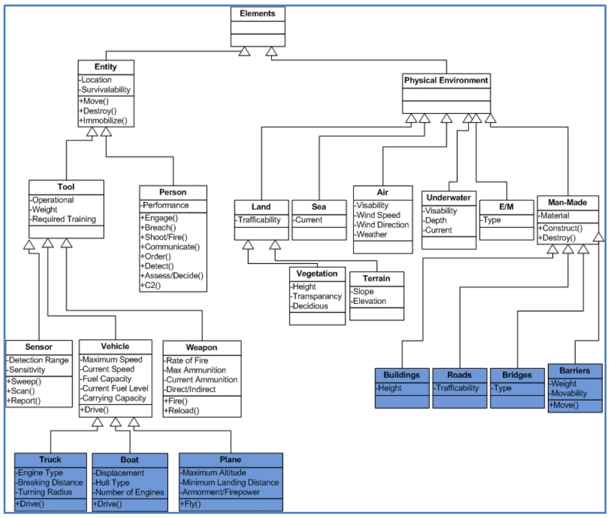

Figure 1: Fidelity Framework

The Fidelity Framework in FIGURE 1 has three key aspects: ***Objects*** (Person, Terrain, and Weapon), ***Attributes*** (Weight), and the Object's associated ***Behaviors*** (Engage). Objects are representations of a model marked by attributes and their associated behaviors. Attributes are the characteristics of an object, defining its state. Behaviors are defined to be the actions that allow an object to change either its own state or the state of another object. This framework can be used when developing a new model in a simulation or assessing the fidelity of existing models in a simulation. The diagram in figure 1 is an example of possible objects that are available for scenario construction for a small arms combat event.

B. Attributes and Object States

The state of an object is defined to be the complete set of the values of its attributes at a given point in time.

We further categorize an object's state into one of four main categories known as the "operational capability of an object":

1. Fully Mission Capable (FMC). An object has all its specified resources and is able to perform all its intended functions.
2. Degraded. An object can perform some, but not all, of its intended functions or an object can perform all intended functions, but at a reduced level of performance.
3. Not Mission Capable (NMC). An object is unable to perform any of its intended functions. NMC and +Degraded objects can be restored to an FMC state, given an infusion of resources.
4. Dead. An object no longer exists and cannot be reconstituted.

C. Behaviors

In our framework a behavior is a dynamic event that involves one or more elements that could result in a change of state of either of the elements. Behaviors are how elements interact. Behaviors are essential in determining the level of fidelity for an element and the capability of a simulation. For example, the behavior of *Move* in low fidelity would be just a change of location for an entity, such as a truck (a vehicle). The behavior of *Move* in high fidelity would account for terrain, vehicle capability to go off road, and driver performance (training). This combination would further be categorized as an interaction.

D. Interactions

Interactions are defined in our Fidelity Framework as the subset of behaviors associated with objects that involve two or more elements

An increase in the number of interactions in a simulation can be described as a product of: 1. the number of simulated objects that are proven to be relevant towards the outcome and, 2. the number of attributes that each (relevant) simulated object has that relates to an intended model. These relationships are categorized in the next section in order to create a ranking system that can be used to determine the level of fidelity present in a simulation's objects and in its design.

III. Ranking of Fidelity in a Simulation

This study evaluated the fidelity of a small arms combat scenario intended for simulation with a focus in three primary areas: models of the objects of interest (state complexity – i.e. extensiveness of definition), interactions between models (behavioral complexity), and the quality of the data that populate these model's attributes (data that is shown through some process as accepted to be both applicable and valid).

The process used to apply the criteria listed below involves looking at a specific element and asking a set of relevant questions that bring into focus both its level of complexity and accuracy in an attempt at modeling an intended reality. Some important distinctions must be explicitly stated at this point.

All models are abstractions of reality; further, all models have an intended purpose with no model being completely accurate. The intended purpose may not be an ideal reality but an intentional elaboration or embellishment of reality (primarily used in training and "what-if" scenarios).[4]

A. Ranking Criteria for Fidelity

For the intent of this paper and the scenario in Section V. we assign a mapping of high, medium, and low fidelity to elements based on the criteria scale below such that:

- High = 4 or 5 on the criteria scale
- Medium = 3 on the criteria scale
- Low = 1 or 2 on the criteria scale

Where the Criteria Scale is:

1. The element exists and has location and a capacity to be detected or observed.
2. The element is capable of changing its state or the state of another element. This implies that it contains attributes that can be acted upon by either internal or external functions (interaction).
3. The element is capable of involvement with other entities and the physical environment in ways that are in addition to just location. This involvement can include being the initiator or receiver of behavior that changes the state of itself, other entities, or physical environment objects.
4. The element contains a high level of complexity in its modeling (seen as an increase in the number of attributes and interactions). The level of complexity of the element is seen as a well-designed, well-implemented, and well-documented methodology that directly follows from an intended concept of reality that has also been well documented. [1]
5. The element contains a high level of complexity in its modeling (seen as an increase in the number of attributes and interactions). This complexity is also coupled with accurate data. The accuracy (correctness and applicability) of the data and behavior (actions) have been verified with respect to the intended model of reality. The accuracy has been documented using well-established means of measurement and accepted validation methods for comparison to an intended and desired reality.

The next section discusses the roles of data, models, and behaviors with respect to these criteria.

IV. Basis of the Ranking

Accuracy and interactions form the basis of the proposed ranking system of fidelity. Accuracy is determined by two factors: applicability and correctness of data (fidelity of a model). Interactions are determined by the relationship of the behaviors of objects (models) in a simulation and their number (fidelity of a simulation).

This section is intended to highlight issues with data that may be driving factors in the accuracy of a scenario, and therefore the intended purpose. The quality and relevance of data impacts and relates primarily to Criterion 5 on the criteria scale. Fidelity is discussed at the end of this section in terms of data accuracy and system complexity (interactions).

FIGURE 2 is a representation of the relationship between correctness and applicability of data and how an increase in each leads to an increase in accuracy.

A. Data Accuracy

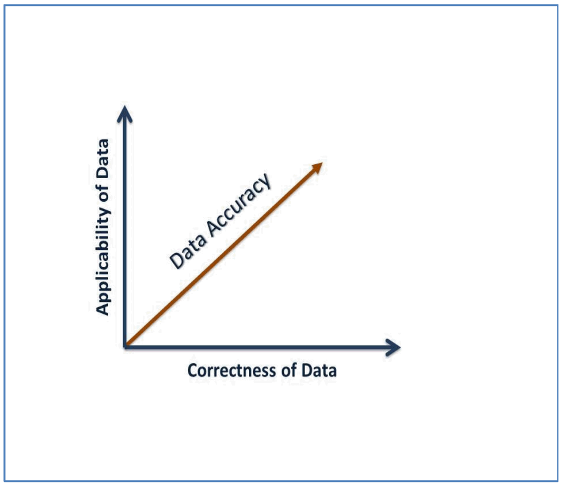

Figure 2: Correctness, Applicability, and Increasing Fidelity

We define accuracy of data to be a measure of the correctness and applicability of the data to represent the intended model of reality (both in its state and as a basis for its behavioral functions). The data of a model are considered applicable if when it is applied in an appropriate manner, that data leads to the expected behavior and intended state of an object (how the data are used or applied). Data are considered to be correct if it is from an appropriate source and valid for the situation (what data are used). When all the data for a developed model are correct and applied appropriately, and the model meets its intended purpose, then accuracy of data are considered to be high.

B. Interactions and Complexity

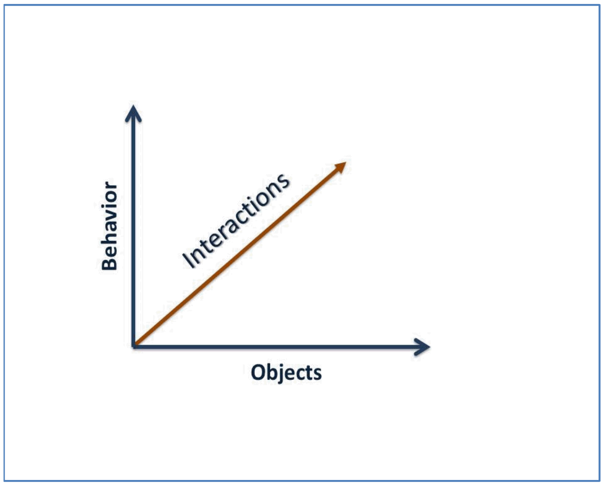

Figure 3 – Increase in the interactions of a system as a result of complex behavior usage

The number of interactions between objects serves as a major indicator of complexity. As the number of relevant objects increases in the system, and their behaviors become more complex to involve other objects (both in number and quality), an increase in the complexity of the system is observed, as shown in FIGURE 3. This increase in complexity is referred to as the number of interactions and is applicable to both object and system level analysis.

C. Fidelity and Complexity

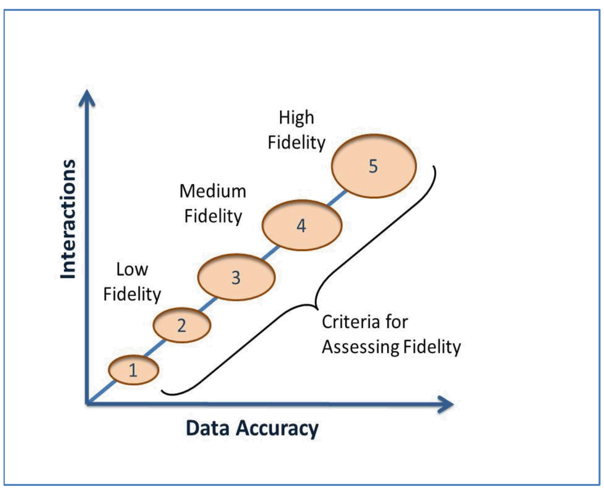

Figure 4 – Primary driving factors leading to an increasing in fidelity

The fidelity of an object or system's model is a measure of the similarity to an intended reality. Fidelity exists in the design of the abstract model as well as in the implementation of that model (object). Some assumptions are necessary to solidify the methodology for applying higher levels of fidelity to systems and objects. First, the intended reality being modeled is assumed to be close to a live or intentionally skewed event. Therefore the reality is complex in nature and reliant on an interdependency of multiple object models that work together to generate some output that is meaningful and relevant. Second, the accuracy of the data used as input to the models is assumed to be high. When accurate data are used in conjunction with the correct level of complexity of behavior in a model, a high level of fidelity is achieved, as shown in FIGURE 4.

V. Case Study: Simple Attack Scenario

The purpose of this case study is to serve as a general example, using the framework and criteria to demonstrate how to arrive at an assessment of fidelity. The security forces (defenders) are going to respond in accordance with their tactics, techniques, and procedures (TTPs). These procedures and capabilities vary by organization and from site to site. The adversary will execute their mission as planned and rehearsed. The scenario is intentionally general, but it can be used by the reader as the basis for a more detailed development to meet a need.

The scenario assumes that the primary adversary is initiated at a physically robutst perimeter system of sensors, barriers and entry control points that protect a high value target. The level of actions that take place in each phase of the attack and the outcomes, which ultimately determine success or failure of adversary and security forces, are depicted in three primary phases seen in FIGURES 5, 6, and 7. This attack path is only one of many and we explore it only to demonstrate the application of our Fidelity Framework to a problem. There are other potential outcomes of this scenario that are not explored such as when a truck bomb fails to detonate, or the adversary (carrying guided weapons) is killed and the weapons are not picked up by another adversary entity. Alternatively, an adversary's guided weapon could miss the target when fired. All these events singularly or in combination are examples that could constitute mission failure for the adversary force (no figure shown).

A. Phase 1 - Initiation

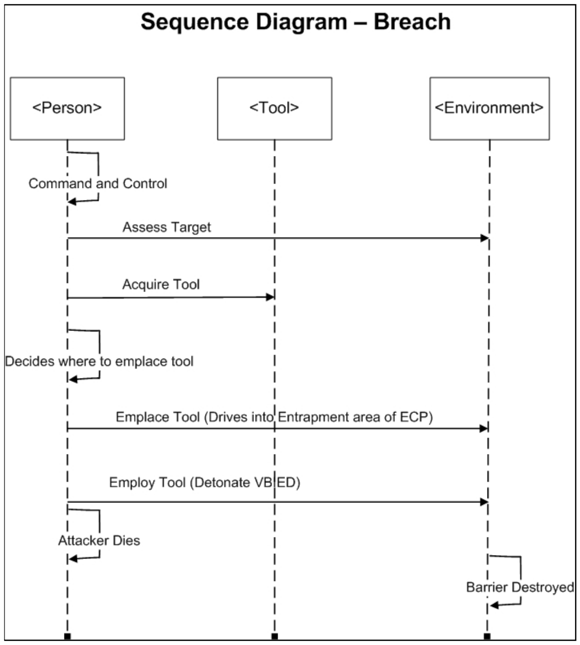

Figure 5 – Initial breach action

Using deception, the adversary penetrates the area and drives a truck bomb to a designated Entry Control Point (ECP). Once at the desired location, within or near the ECP, the driver initiates the explosive device, killing himself and other personnel in the area. The explosion breaches the ECP and damages/destroys surrounding structures, as shown in FIGURE 5.

B. Phase 2 - Penetration

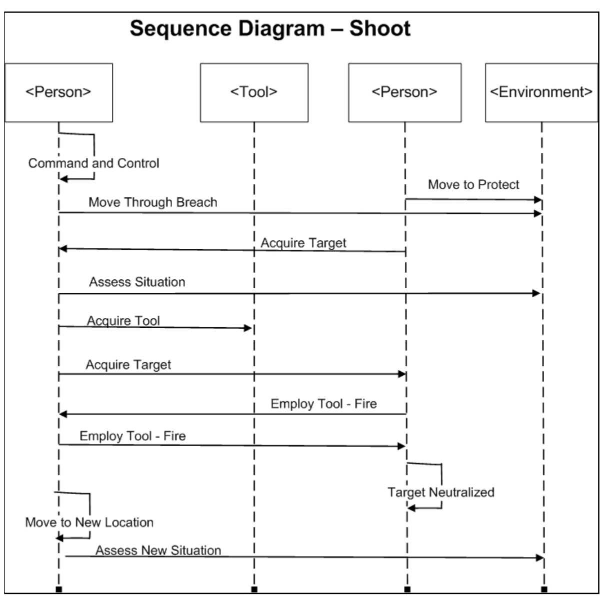

Figure 6 - Interactions after Breach

After the explosion the primary adversary attack force, which also penetrated the area using deceptive techniques, is waiting in a safe area (in a building or in vehicles) not far from the targeted ECP, and out of the blast radius of the truck bomb. They then proceed by foot or vehicle to and through the breached area, engage the security forces using small arms and grenades (Figure 6.), while proceeding to stand-off firing positions overlooking the main target/objective. The indication of the *person* object in our sequence diagrams is of either the adversary or security team member depending upon the particular interaction sequence of events. The sequence diagrams are meant to be used as generic tools that are applied to a situation in which the instigator is the first *Person* object and the second person object is the opposing force reacting to the event.

C. Phase 3 – Target Engagement

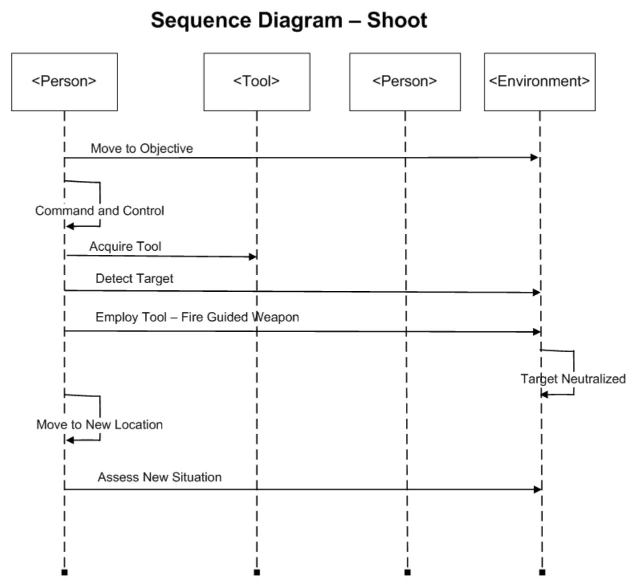

Figure 7 - Interactions upon arrival at designated firing positions

Upon arrival at the designated firing position, the surviving adversary forces provide security for personnell operating the guided weapons, who deploy and prepare the weapons, and engage their primary target. The guided weapons are fired at the main target, as shown in FIGURE 7.

After firing the guided weapons, the surviving adversary forces begin to escape and evade (E&E) to pre-determined rendezvous areas outside the Area of Operations. (Marked as "*Assess New Situation"* in the sequence diagram of FIGURE 7).

VI. Application of Fidelity to the Case Study

Using the rankings described in section III., we can apply the fidelity mapping described for the case study laid out in Section V.

For this scenario we generate the following information:

High fidelity is required for [5]

- Explosive Breaching Charge- The decision was made that high fidelity was needed for Breach because we want to know the effect of blast and fragmentation damage to the target, personnel and the surrounding areas. In addition we ask: does the detonation allow the adversary to penetrate the breach at the entry control point (ECP) either in a vehicle or on foot?
- Move - involves movement, carried equipment, terrain features. Can adversary forces drive through the breach or must they dismount and move through on foot carrying their equipment? How fast can the adversary move? How fast can security forces respond, intercept, and neutralize? This also implies that any engagement between security and adversary forces may affect the timeline for the adversary reaching the target and security forces preventing the adversary from reaching the target.
- Guided Weapons - High fidelity is also needed for guided weapons. We want to know the operator's ability to use the weapon and the weapon's performance characteristics from initiation to impact.
- Targets - We want to know the target's interaction with the guided weapons that will be used against it.
- Ultimately, we want to know the response capabilities and timelines of security forces versus the adversary.

Medium fidelity is required for

- Primary Weapons
- Vehicles

Medium fidelity is used in this scenario for all adversary forces and security forces primary weapons (Machine Guns, Assault Rifles, Side Arms, and Grenades). The fidelity will be met using weapons data from existing human factor and performance sources.

In addition, medium fidelity is required for security and adversary force vehicles. We want to know their terrain capabilities, speeds, and survivability (Armor) when engaged with weapons fire.

Both of these medium fidelity requirements, when combined with the high fidelity requirements, will begin to refine and bring into focus the potential analysis that can be performed from the technical aspects of the scenario dynamics. These aspects are derived from the models found in a refined version (not shown) of the Tools and Physical Environment categories in the Fidelity Framework.

Low fidelity is required for

- Adversary and security force personnel
- Communications
- Basic individual load-outs

Low fidelity is chosen in this scenario for all individuals because we assume a simplified cognitive model that is in the form of scripted behaviors. We have purposively chosen not to model motivation, decision making, or other aspects of cognition. In our example, all forces are highly automated and are expected to have expert equipment, weapons, and tactical behaviors.

The reasoning underlying the choices for fidelity in this scenario is based upon a fictitious end-user's needs that rely on combat physics and positional information to be used for future planning and analysis. It is important to recognize that, when attempting to apply any level of fidelity to models in either a modeling and simulation tool or a particular scenario, a repeatable process must be identified and followed (not described in this paper) that looks at both:

1. The end-use needs of any analysis performed. This verifies that what one chooses to simulate and examine (the type of analysis performed) coincides with what that analysis will be applied to.
2. An identification of the critical or otherwise driving factors involved in a simulation or scenario. Understanding what the driving forces of an event are and how they work (usually identified by Subject Matter Experts) are what gives credibility and meaning to any performance criteria related to simulation tools or developed scenarios.

Additional factors that should be identified in Modeling and Simulation tool use should also include that the data used in the scenario are assumed to be current and within reliable ranges. Thus interactivity will increase complexity and the fidelity of the scenario. In this way, additional factors and effects are demonstrated that may contribute to the characterization of an adversary's ability to carry out their intended mission.

VII. Summary

This fidelity framework focuses on creating, judging, and assessing fidelity in models and simulations involving small unit combat models. It is general enough to capture combat concepts, but not so specific that the user is tied to a particular event. The framework is meant to evoke thought and provide a basis for judging what level of fidelity should be required for particular objects in a scenario (and therefore supplied by the modeling and simulation tool) based on the intended purpose of the model and the end-user's application of its analysis. The scenario should match the intended reality of interest required by the end-user. In many cases, this is a qualitative judgment by a program manager. The question must be addressed: what reality is important and applicable, before a judgment about fidelity can be made. Key steps in addressing this design decision are: 1. What reality do we need to simulate, 2. Can we simulate this reality to a satisfactory level that meets our analysis needs, with special attention on modeling the correct data and interactions, and 3. If we can not model to our intended reality, what assumptions/concessions are we willing to make in the construction and analysis to achieve our end goals while noting our limitations and constraints?

It is important to note that the often desired high level of fidelity in a MOD-SIM analysis (and therefore simulation) is almost always limited by a project's resources. It is the selection of a simulation's critical drivers that are most difficult to identify for providing success in developing a meaningful analysis of the simulation's output data.

Acknowledgment

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