Weapon effectiveness models: are they appropriate for use in force protection analyses?

F. A. Maestas & L. A. Young
Applied Research Associates, Inc., U.S.A.

Abstract

The Department of Defense has developed numerous weapon effectiveness tools that have been successfully used in evaluating the performance of military warheads against enemy above-ground and underground targets. Tools such as the Air Force Research Laboratory's (AFRL's) Modular Effectiveness/ Vulnerability Assessment (MEVA) code and the Defense Threat Reduction Agency's (DTRA's) Integrated Modular Effectiveness Analysis (IMEA) code embody algorithms for blast and fragment environment characterization, structural response analyses, and equipment and structural fault tree assessments, Young, York [1, 2]. Additional analysis tools like the Extended Collateral Damage (ECD) Methodology, developed to support a number of applications, also include algorithms for predicting personal injury and death, Whitehouse [3]. Because physical security assessments share the need for modelling blast and fragmentation effects on structures and personnel, one approach to cost-effectively advancing physical security code capabilities is to apply existing weapon effectiveness codes to defensive purposes. This paper examines the technical issues associated with attempting this type of technology transition, and makes recommendations for addressing the technical issues that arise from the differences between weapon effectiveness and physical security applications.

Keywords: weapon effectiveness, survivability analysis, modelling and simulation, physical security analysis, personnel security.

1 Introduction

In recent years, physical security and force protection specialists have been obligated to make costly and potentially life-saving decisions regarding blast mitigation strategies and equipment, structural designs and retrofits, site planning and security protocols, for increasingly complex environments and in response to increasingly aggressive adversaries. To support these decisions, some organizations have sought to use Department of Defense weapon effectiveness tools such as the US Air Force's Modular Effectiveness Vulnerability Assessments (MEVA) code, the Defense Threat Reduction Agency's Integrated Modular Effectiveness Analysis (IMEA) code and the Extended Collateral Damage (ECD) Methodology.

Typically, weapon effectiveness tools embody algorithms for modeling blast and fragmentation effects on structures and personnel. MEVA, for example, was designed to assess the survivability/vulnerability of fixed underground hardened targets subjected to conventional weapon attack. The assessment is accomplished by modeling the attack or delivery conditions, the penetration event, weapon fuzing, and detonation effects in Monte-Carlo-type calculations. Of the key modules in MEVA, Facilities Modeling, Weapon Penetration, Blast and Fragment Propagation, Structural Collapse, Cratering, Equipment Damage, and Hazardous Agent Dispersion; all but the Weapon Penetration module has potential applicability in force protection and physical security environments.

Although the obvious efficiencies associated with using existing tools are appealing, such repurposing should not occur without an objective assessment of not only the individual algorithms in a weapon effectiveness code, but also the assumptions inherent in the overall model.

Table 1: Required capabilities.

Function	*Weapon Effectiveness Tools*	*Force Protection Tools*
Target Modeling	CAD/2-3 D/	CAD/2-3D/
Weapon/Threat		
Blast	TNT standard	TNT standard
Fragmentation	Explicitly flown	Impulse added to blast
Hazardous agent dispersion	Fate modeled	N/A
Structural Response		
Collapse	Detailed or SDF	Detailed or SDF
Wall damage	Impulse/Pressure based	Impulse/Pressure based
Structural Debris Dispersion	Heuristics, based on Wall damage	Heuristics, based on Wall damage
Cratering	Modeled	N/A
Functional Evaluation	Fault tree	N/A
Personnel Injury	Primary blast, primary fragment penetration, window shard penetration, estimations based upon structural damage	Primary blast, primary fragment penetration, window shard penetration, secondary debris penetration and blunt trauma
Personnel Incapacitation	Low-fidelity incapacitation criteria based upon injury probabilities	N/A

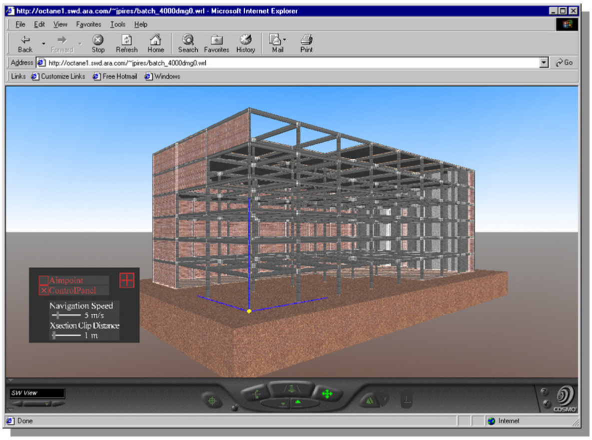
2 Comparison between weapon effectiveness and force protection modeling requirements

Table 1 provides a listing of the general capabilities required by weapon effectiveness and force protection models, presenting an overview of some of their similarities and differences.

2.1 Similarities between weapon effectiveness and force protection models

The temptation to use weapon effectiveness models for physical security and force protection applications arises from similarities in the core components of both types of codes.

For example, at the heart of both types of models, there must be relatively sophisticated building models. As shown in Figure 1, the building models typically must include major components such as floors, walls, columns, beams and windows, and for frangible aboveground structures, structural joints. With this level of detail, it is possible to model not only the propagation of blast around or within a structure, but also to model the interaction of the blast with the structure. Key to both types of models is the requirement for materials properties linked to the building model so that damage may be accurately evaluated.



☐ Aimpoint
☒ ControlPanel
Navigation Speed 5 m/s
Xsection Clip Distance 1 m

Figure 1: Example of weapon effectiveness analysis of above ground building, damage predicted.

In addition, both weapon effectiveness and physical security codes need algorithms for fragment fly-out. Typically, weapon effectiveness codes model fragment fly-out using a stochastically generated set of weapon fragments, based upon either Arena test data files or Mott's distribution, with initial velocity and trajectory data based upon the weapon velocity at detonation and, again, either Arena test data or Mott's distribution [4, 5]. Fragments are projected from the weapon, and damage to walls, equipment and personnel is based upon fragment and fragment impact conditions (Figure 2).

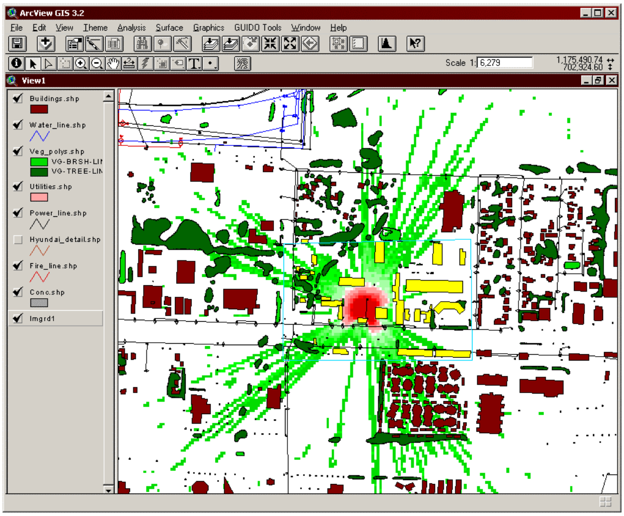


Figure 2: Example of fragment impact locations, with estimated injuries to civilians.

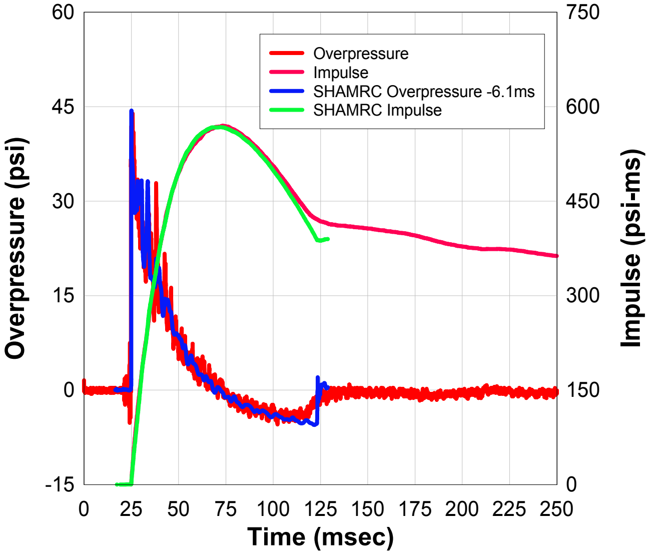


Figure 3: Example of calculated pressure and impulse time histories.

Similarly, both weapon effectiveness and physical security codes need algorithms modeling blast. The level of fidelity in blast models varies somewhat from code to code. Most weapon effectiveness models provide analytical approximations for the shock(s) that result from the detonations. These blast pressure time histories for both the static (side-on) pressure and dynamic pressure environments are evaluated. The peak pressures, time histories and the integration of the time history (impulse, Figure 3) are used as loads on the structure, equipment and inhabitants. These blast models are generally only appropriate for conventional high explosives and are used to generate the ideal, free-field weapon form, (Needham and Crepeau [6] and Kingery and Bulmarsh [7]. To model the reflection of blast off walls and other rigid structures, optical reflection is assumed, (Hacker and Dunn [8], Britt and Little [9] and Hikida and Needham [10] (Figure 4).

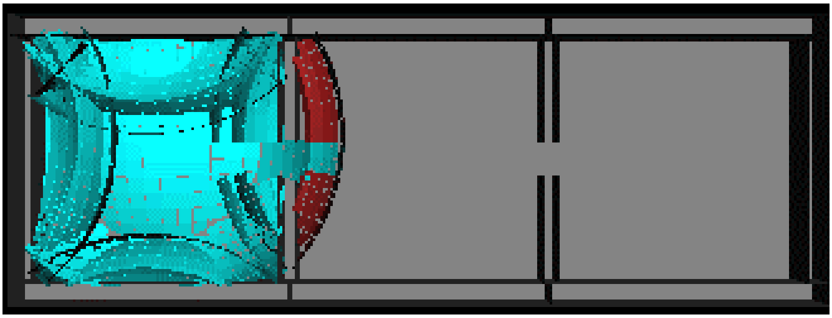


Figure 4: Example of internal blast reflection and propagation inside building.

Finally, both weapon effectiveness and physical security codes must function stochastically. For weapon effectiveness codes, this requirement stems primarily from realistic variability in weapon impact conditions, uncertainty in target knowledge and variability in the weapon yield. For physical security codes, the analyst typically designs to a chosen weapon yield and assumed source location, and the analyst's knowledge of the structure generally surpasses the required fidelity of the building model. However, for physical security codes, a stochastic modeling approach is essential to capture the high degree of inherent biological variability in humans, and the consequential variability in their response to blast.

Both weapon effectiveness and force protection codes model structural response using pressure impulse techniques [11]. The damage to walls, beams and columns are typically explicitly modeled. The loads determined from the time history approximations, modified for reflections and integrated to obtain impulse are compared to the structural capacity of the various structural members to determine damage. The damage is accumulated and used for evaluation of structural and personnel response.

2.2 Differences between weapon effectiveness and force protection modeling requirements

Although weapon effectiveness and force protection codes share many modeling requirements, there are philosophical, functional and technical differences that must be acknowledged before attempting to repurpose weapon effectiveness codes.

The most fundamental philosophical difference between weapon effectiveness and force protection codes is the assumption of acceptable bias. In a weapon effectiveness code it is usually desirable to err on the side of under-estimating weapon effects, thus minimizing the probability of risking pilots and planes on underwhelming attacks. For physical security and force protection purposes, on the other hand, it is usually desirable to err on the side of over-estimating weapon effects, thus minimizing the risk to personnel in the event of an attack. Collateral damage methodologies, such as ECD, are an exception to these trends. Although these codes are basically weapon effectiveness codes, they are designed to err on the side of over-estimating weapon effects, thus minimizing the probability of unexpected civilian injuries in a military attack. In both weapon effectiveness and physical security codes, the acceptable direction and magnitude of error is implicit to the underlying assumptions of the blast, fragmentation and blast-structural interaction algorithms.

Another fundamental philosophical difference between weapon effectiveness and force protection are the measures of effectiveness. Typically, weapon effectiveness codes are used to quantify results in terms of structural and equipment damage. Probability of structural kill statistics report the probability of some percentage, usually 50% or 100% of the target's structure being damaged in an attack. Probability of functional kill statistics report the probability of either some percentage of equipment being disabled, or the probability of specific mission-critical equipment being disabled. Although the historical focus of force protection and physical security analyses has been on structural damage, in the last ten years, the interest in structural effects has become secondary, and only usually considered relevant to the extent that structural damage is indicative of blast effects on human (i.e. "bio-effects"). Again, collateral damage codes, such as ECD, are exceptions to this rule, since collateral damage is measured at least as much by bio-effects as by structural damage.

The difference in measures of effectiveness needed by the weapon effectiveness and force protection analysts arises out of the fundamentally different *functions* of weapon effectiveness and force protection models. Weapon Effectiveness models are typically used for mission planning, weapon design and development (analysis of alternative studies, fuzing, etc.), and OCONUS and CONUS protected structure design. Physical Security models are currently used primarily to make decisions about safe standoff distances and structure design and retrofit cost/benefit decisions. The community has a long-term goal of developing the Physical Security models to the extent that they can also be used to assist in medical response (and other first responder) preparedness. Because of the different applications, when Weapon Effectiveness models *are* employed to look at effects on humans, they are typically only interested in a binary answer, dead or not dead, or perhaps the more rigorous models are interested in the five-minute assault criterion, which is concerned with the level of incapacitation within five minutes of the attack. The most rigorous models are concerned with injuries only to the extent that they are indicative of operational casualties (is the soldier able to shoot his gun after the attack, e.g.). Physical Security models, on the other hand, are almost never satisfied with the binary dead/not-dead answer, and they are almost always applied to civilian or non-combatant warfighters, in which case operational casualties are irrelevant and "incapacitation" is not clearly defined. Instead, physical security models are usually concerned with the type and severity of injuries, as a function of time (Figure 5). They require much greater fidelity in this respect than the weapon effectiveness models were ever intended to provide.

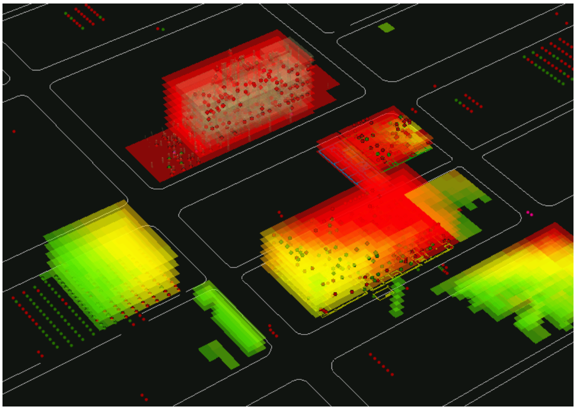


Figure 5: Example of injury probability model compared to data.

The technical differences between weapon effectiveness and force protection models arise naturally from their functional differences. One of the most significant technical differences between weapon effectiveness codes and force protection problems is the "source term." Historically, Weapon Effectiveness models have been designed to function with bare charges and inventoried (or future inventoried) weapons. Force Protection and Physical Security analysts, on the other hand, are concerned not only with inventoried weapons, but also Improvised Explosive Devices (IEDs). At a relatively short scaled distance from ground zero, the difference in blast waveforms in IEDs and weapons with similar explosive mixes will generally be negligible. However, the difference in primary fragments from inventoried weapons and IEDs is usually profound. Although there is certainly a fair component of randomness in the case break-up, inventoried weapons typically have reasonably well-characterized weapon fragmentation patterns. IEDs, on the other hand, are by definition much less defined. The fragment distribution from a steel pipe bomb will differ dramatically from that of a large vehicle bomb, and still more differently from a typical suicide bomb packed with screws, nails, bolts and glass fragments. Because fragment penetration is the greatest source of blast injuries (not deaths) from IEDs, characterization of the unconventional fragments of an IED are particularly significant to evaluating the bio-effects of blast in physical security and force protection analyses.

Another important technical difference is the importance of secondary blast effects, particularly window breakage and secondary, structural debris. Because window fragment penetration is only rarely lethal, and is never a primary attack objective, most weapon effectiveness codes do not include window models, except to account for blast venting. However, in the event of a blast in an urban environment, window fragment penetrations (Figure 6) and structural debris injuries can be a significant concern. In fact, in the A.P. Murrah bombing in Oklahoma City, glass fragment penetrations accounted for approximately 39% (200 of 508) of the non-lethal injuries to persons not located inside the Murrah building, Norville [12]. Blunt trauma from structural debris accounted for 17 of 19 deaths in the Al Khobar Tower bombing, Downing [13].

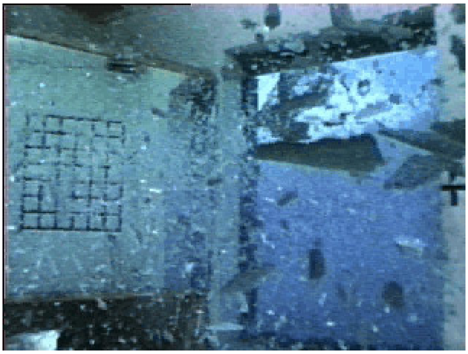


Figure 6: Example of glass debris.

3 Important trends

As military operations are increasingly fought on an urban terrain and as our opponents increasingly use terrorist tactics, as opposed to traditional military tactics, the difference between Weapon Effectiveness and Physical Security codes will begin to narrow significantly, increasing both the overlap between these two types of tools, and the level of fidelity required by each.

One major trend impacting both types of tools is a transition to new blast weapons. Operation Iraqi Freedom is a reasonable indicator for future conflicts, where “weapons of terror are still the method of choice for the opposition. IEDs and vehicle-borne improvised explosive devices (VBIED) are the weapons of choice.” Downing [13] IEDs are currently being employed by Iraqi insurgents at a rate of approximately 40 per day. At this rate, weapon effectiveness codes used in the design of protective structures will share in the physical security codes’ need for new source term models and new fragment characterization models. On the other hand, as many of the IEDs are constructed using unexploded inventoried ordnances, physical security codes have begun to share the weapon effectiveness codes' need for conventional weapon models. As enhanced novel explosives, such as thermobarics, become increasingly common, both as inventoried and improvised weapons, both weapon effectiveness and physical security codes will require new source term models capable of capturing the effects of unconventional explosives.

The propagation of enhanced novel explosives will not only affect the source term models in weapon effectiveness and force protection codes, but it will also affect the measures of effectiveness for weapons effectiveness codes and the level of fidelity required for both structural and bio-effects in both types of tools. Enhanced novel explosives are typically not designed as fragmenting weapons, but are instead designed to accomplish their objective through longer-duration, multiple pulse blast waves. These enhanced blast waves have the potential effect of increasing the radii of both structural damage and lethal blast pressures surrounding the detonation. The increased impulse output of enhanced novel explosives will require that both the weapon effectiveness and force protection codes substantially improve the fidelity of their structural debris and shock venting engineering models. In addition, because enhanced novel explosives are generally designed to target personnel, rather than structures or equipment, weapon effectiveness tools will have to adopt personnel injury and incapacitation measures of effectiveness and higher fidelity blast injury models.

4 Conclusion

Weapon effectiveness and survivability have long been understood to be "two sides of the same coin." As asymmetric warfare, urban conflicts, terrorism and enhanced novel explosives become more prevalent, the technical distinctions between weapon effectiveness and force protection and physical security codes will diminish. However, for weapon effectiveness tools such as MEVA and IMEA to be repurposed for physical security purposes, the direction and magnitude of bias implicit in the blast, fragmentation and blast-structure interaction algorithms must be somehow extracted or, at least, quantified.

References

[1] Young, L.A., Streit B.K., Peterson, K.J., Read, D.L. & Maestas, F.A., *Effectiveness/Vulnerability Assessments in Three Dimensions (EVA-3D) Versions 4.1F and 4.1C User's Manual - Revision A*. Technical Report SL-TR-96-7000 prepared by Applied Research Associates, Inc., for U.S. Air Force Wright Laboratory, November 29, 1995.

[2] York, A.R. & Harman, W., "Integrated Munitions Effects Assessment: A Weapons Effects and Collateral Effects Assessment Tool," NBC Report, U.S. Army Nuclear and Chemical Agency, pp 30-37, Spring/Summer 2003.

[3] Whitehouse, S.R., et. al., *Extended Collateral Damage (ECD) Analyst Manual*, Prepared for Naval Surface Warfare Center, Dahlgren Division, Code J31, Contract No. N00178-97-D-3037, Prepared by Applied Research Associates, Inc., 4300 San Mateo Blvd. NE, Suite A-220, Albuquerque, NM 87110, November 1999.

[4] Joint Munitions Effectiveness Manual, Air-to-Surface, *Weapon Characteristics*, *JMEM (U), 61A1-3-2, Revision 4,* 11 February 1994 (CONFIDENTIAL Report).

[5] "Fragmentation Characteristics and Terminal Effects Data for Surface-to-Surface Weapons (U), 61S1-3-4" (CONFIDENTIAL Report).

[6] Needham, C.E. & Crepeau, J.E., "The DNA Nuclear Blast Standard (1KT)," DNA 5648T, prepared by S-Cubed for the Defense Nuclear Agency, Alexander, VA, January, 1981.

[7] Kingery, C.N. & Bulmash, G., "Airblast Parameters from TNT Spherical Air Bust and Hemispherical Surface Burst," Technical Report ARBRL-TR-02555, U.S. Army Armament Research and Development Center, Ballistic Research Laboratory, Aberdeen Proving Ground, MD, April 1984.

[8] Hacker, W.L. & Dunn, P.E., "Airblast Propagation and Damage Methodology," Final Report, AMSAA Contract No. DAAA15-94-D-0005, Delivery Order 0013, Applied Research Associates for U.S. Army Research Laboratory, AMSRL-SL-B, Aberdeen Proving Ground, MD, April 1997.

[9] Britt, J.R. & Little, C.D., Jr., "Airblast Attenuation Entranceways and Other Typical Components of Structures, Small-Scale Tests Data Report 1," Technical Report SL-81V-22, U.S. Army Engineer Waterways Experiment Station, 1984.

[10] Hikida, S. & Needham, C.E., "Low Altitude Multiple Burst (LAMB) Model, Volume I-Shock Description," DNA 5683Z-1, prepared by S-Cubed for the Defense Nuclear Agency, Alexandria, VA, June 1981.

[11] *Facility and Component Explosive Damage Assessment Program (FACEDAP), Theory Manual, Version 1.2*, Contract No. DACA 45-91-D-0019, U.S. Army Corps Engineers, Omaha, NE, May 1984.

[12] Norville, H.S., Conrath, E.J., Shariat, S. & Mallonee, S., "Glass-Related Injuries in Oklahoma City Bombing," *Journal of Performance of Constructed Facilities*, May 1999.

[13] Downing, WA, "Report to the President and Congress on the Protection of US Forces Deployed Abroad: Annex A: The Downing Investigation Report," August 30, 1996.