Chapter Eight

CONCLUSIONS

RECALLING OBJECTIVES

At the start of this report, we gave our purpose as describing analytically how the effectiveness of long-range precision weapons should be expected to vary when used against a moving armored column, depending on variables usually treated only in much more complex models. We considered:

- Characteristics of the Blue C^4ISR system;
- Characteristics of the Blue weapon systems;
- Maneuver pattern of the advancing Red armored column;
- Terrain features; and
- Blue tactics, including salvo offsets.

OBSERVATIONS

These factors can make a huge difference in the effectiveness of long-range precision fires, as measured by kills per salvo or sortie. Consider the "standard" target for such fires to be a column of armored vehicles separated randomly but typically by no more than 50 meters, traveling across terrain that offers no concealment (e.g., the desert). Long-range precision fires can be extremely effective against such a standard target. When the above factors are varied, however, kills per salvo may be reduced by one or two orders of magnitude.

Moreover, these factors interact. One cannot model the influences of these factors in a simple way—for example, as a product of a terrain adjustment, a Red dispersion adjustment, a C4ISR adjustment, and so on. The sensitivities of outcome to one factor depend strongly on other factors, and linear sensitivity analysis around some baseline would be misleading. Thus, we need to use exploratory analysis to characterize how the factors combine to dictate Blue success or failure.

The Red maneuver pattern, which can reflect a passive Red countermeasure against the Blue attack, interacts with several of the other factors. Changing the Red maneuver pattern has a much greater effect in terrain with small open areas than in terrain with large ones. Also, changing the maneuver pattern (particularly the AFV spacing within a packet) is more important for weapons with small footprints (SFWs) than for those with large footprints (ATACMS/BAT). However, a weapon with a large footprint loses its advantage over a weapon with a small footprint in terrain with no large open areas to shoot at.

Depending on the other factors, the time since last update (a primary C4ISR parameter) can range from very important to completely irrelevant. In PEM, the time since last update influences the results through its effect on the time-of-arrival error of the Blue missile, and NOT through an effect on a spacial error in the impact point. If Red maneuvers in long columns of uniformly spaced vehicles, then kills per salvo are the same regardless of the time since last update because the column looks the same regardless of when the missile arrives. But if Red changes his maneuver pattern, it becomes important for Blue to place his shots on target precisely when the Red packet arrives. Accurate timing of shots becomes even more important if open areas are small, at least in the sense that kills per shot decline by a larger fraction as time since last update increases. But if open areas are small enough, kills per shot may be too meager for shooting to be worthwhile even if the time since last update is zero, especially if weapon-descent time is long.

If the Red formation maintains strict discipline and moves with constant speed, then prediction will be easier. A small time since last update will pay dividends. But if Red is less organized or deliberately changes speeds, effectiveness may be low even with short times from last update, especially in mixed terrain.

In addition, the ability to discriminate between live and dead targets is important if multiple shots were fired into the same area without leaving time for dead targets to stop and cool or if kills per weapon is high.

Offsetting missiles in time often has only a marginal effect by reducing the likelihood of a second missile attacking a portion of a packet or packet group that has already been depleted. Offsetting the impact point has less effect for large-footprint weapons. In contrast, offsetting SFWs is quite important if they are employed, as suggested by Ochmanek et al. (1998), to “annihilate” the leading edge or nose of an advancing column. Otherwise, dead-target effects (failure to discriminate) would greatly reduce effectiveness. This, however, should be relatively straightforward operationally.

Some subtleties of outcome cannot reasonably be predicted from a PEM-level model. Here are some examples we have noted from high-resolution simulation:

- When ATACMS/BAT is employed against columns at crossroads, kills per shot can be sensitively dependent on the orientation of the columns and roads, and on the weapon logic used. In some instances, the weapon logic is confused by the pattern of signals and the submunitions are laid down on lines intermediate between good lines on the ground containing targets.[1]
- Weapon effectiveness can be sensitive to the level of acoustic noise due to vehicles in the general area, as well as the impact on directional signal-to-noise ratio of terrain. Thus, one cannot calibrate a PEM-like model by simply using a high-resolution model against a single target and then extrapolating. PEM should be considered better for scaling than for exact prediction.

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[1]Initial data analysis suggested that this effect might be a major factor in the overall low effectiveness of weapons in the high-resolution simulations. Subsequently, we have come to believe that microscopic urban clutter, as discussed in earlier chapters, also played an important role in attacks against crossroads.

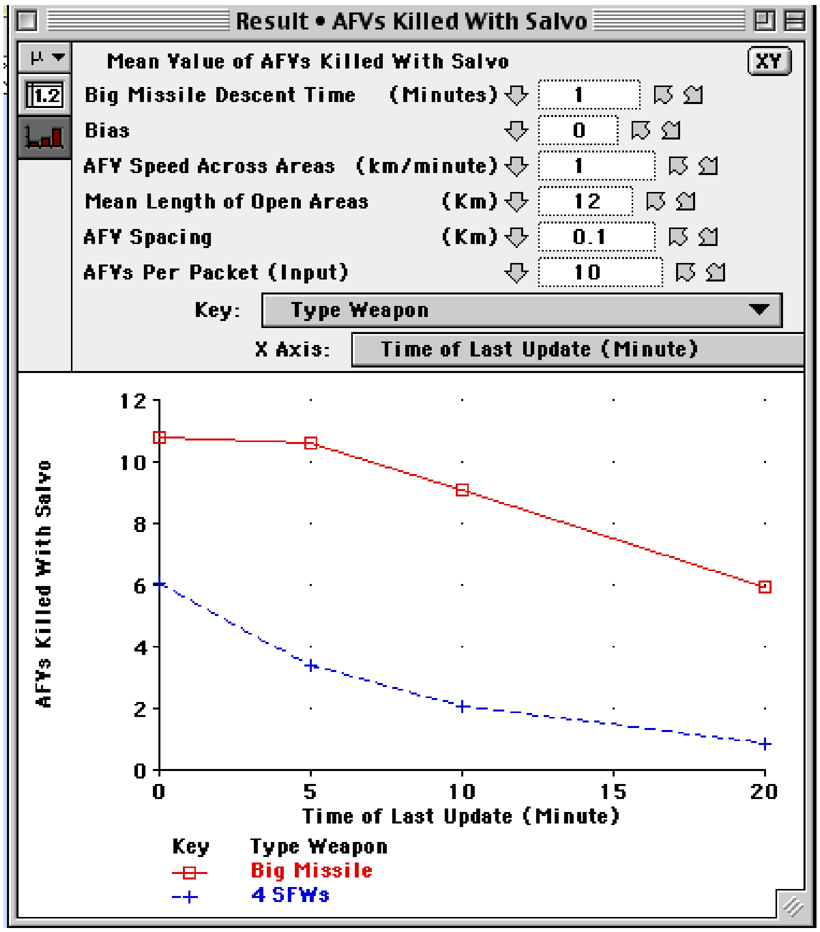
- Many details of operations affect results to some extent. For example, columns may show rigid discipline or may show highly random spacings among vehicles and units.

We have not addressed the issue of Blue doctrine for long-range precision fires, except for the matter of offsetting weapons. Under what circumstances should Blue even attempt to stop an armored column by long-range fires? What weapons should be used against large versus small groups of Red vehicles, or against armored vehicles versus trucks (if Blue's surveillance is capable enough to distinguish vehicle types)? As a stand-alone model, PEM is not suited for examining Blue doctrine, but as a quick and efficient subroutine embedded in a larger model, it may be. The larger model would generate groups of Red vehicles crossing the chosen terrain, and PEM could quickly evaluate the potential of each of several Blue weapons against all the groups as they crossed the various open areas. A wide variety of doctrines could be constructed and evaluated in such a modeling environment.

One might immediately assume that the larger model would be a high-resolution simulation model that tracks the movement of thousands of individual Red vehicles along specific roads in a terrain represented by millions of cells in an XY plane. But this need not be the case. The larger model could instead sample potential target groups from statistical distributions. Such a statistical model might be developed much as PEM was and then calibrated to a high-resolution simulation.

COMPARING WEAPON TYPES

Most of our study has focused on weapons comparable to ATACMS/BAT, but we also considered air-delivered sensor-fused weapons using some performance figures cited in an earlier study (Ochmanek et al., 1998) for the kills per sortie to be expected from an F-16 with four sensor-fused weapons attacking targets in the open. Several observations from applying PEM are of interest here. First, time from last update is much more important for SFWs than for ATACMS/BAT when attacking targets in the desert. Figure 8.1



NOTE: Assumes a 25% error in estimating invaders' average speed along the road between the time of observation and the intended time of weapon impact.

Figure 8.1—Sensor-Fused Weapons Versus BAT in Open Terrain

illustrates this and is qualitatively consistent with results from high-resolution simulation accomplished for a 1996 DSB study (Matsumura, Steeb, Herbert, et al., 1997). The reason behind this, simply, is that the sensor-fused weapons have small footprints.

Thus, if they attack moderately dispersed forces moving in packets, their effectiveness will be sensitively dependent on the timing error. It follows that direct-attack SFWs are currently much more effective than standoff versions such as JSOW.[2,3]

Figure 8.2 shows an illustrative and more speculative result for mixed terrain (3 km mean length of open areas, with other parameters held constant from Figure 8.1). Here we see that the weapon systems both have degraded performance for long times of last update, but the curves are more similar. The reason, for this is that BAT is unable to benefit much from its large footprint because effectiveness is limited by the size of the open areas. Another factor reflected in Figure 8.2 is the effect of BAT's larger "descent time" discussed in earlier

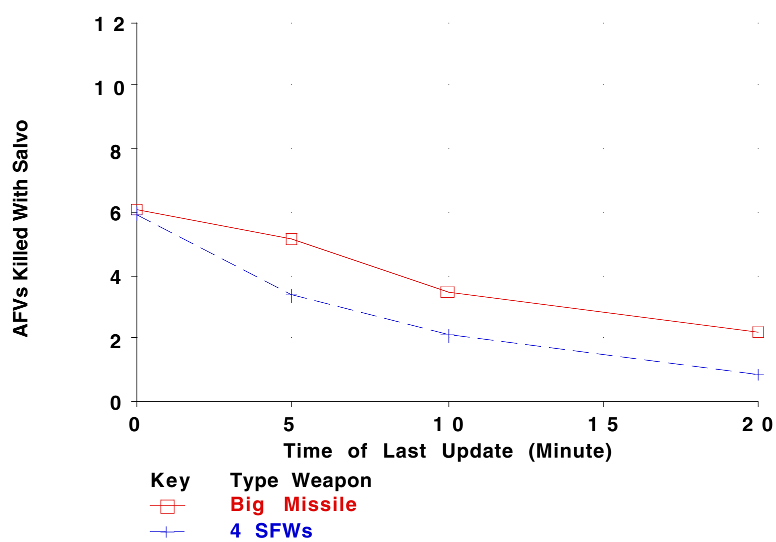


Figure 8.2—Results for Mixed Terrain

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[2]See also a forthcoming RAND study for the Air Force by Edward Harshberger and colleagues. That study examines such weapon issues in considerable detail using high-resolution simulation.

[3]The display shown in Figures 8.1 and 8.2 refers to "Big Missile," by which we mean missiles akin to ATACMS with BAT.

chapters. Such considerations suggest that cost-effective comparisons, when assessing alternative mixes of weapons, need to be conducted quite carefully.

SUMMARY EFFECTS: LOOKUP TABLES FOR USE IN OTHER MODELS

So far, we have described our understanding of phenomenology, a relatively detailed desktop model, and a simplified "repro" model. Tables 8.1 and 8.2 go farther and summarize results of many thousands of PEM runs in estimating the effectiveness of an ATACMS/BAT-like system and an F-16/SFW system versus the attacker's choices of AFV spacing, the type of terrain, and the time from last update for the interdictor's weapon system. Since actual

Table 8.1

Kills per ATACMS/BAT Salvo for 0, 10, and 16 Minutes from Last Update[a]

Dispersal/Terrain	Open	Mixed	Primitive Mixed
No Timing Error			
Very tight	12	10	1
Dispersed	11	6.0	0.2
Very dispersed	6.2	2.9	0.06
10 Minute Errors			
Very tight	12	10	1
Dispersed	9.1	2.2	0.3
Very dispersed	4.9	1.8	0.15
16 Minute Errors			
Very tight	12	10	1
Dispersed	6.0	3.4	0.23
Very dispersed	3.1	1.1	0.15

Definitions: Very tight: 50 meters per AFV, 100 AFVs per packet; Dispersed: 100 meters per AFV, 10 AFVs per packet; Very dispersed: 200 meters per AFV, 5 AFVs per packet. Open: 12 km open-area mean widths; Mixed: 3 km open-area mean widths; Primitive: 1 km open-area mean widths.

[a]These figures assume a factor of 0.25 for the fractional error in estimating maneuver speed along the road. Actual time errors in projecting the arrival of targets in an open area are then four times the numbers shown in the tables.

effectiveness numbers would also depend on details not reported here (e.g., the acoustic environment due to the particular types of vehicles in the march, their configuration, and their interaction with the environment), what matters most is the relative numbers. As can be seen by comparing the top-left and bottom-right figures, we should expect a factor of nearly 100 in weapon effectiveness as a function of these three variables.[4]

Table 8.2 shows analogous results for SFWs, if used in a manner similar to that described in Ochmanek et al. (1998).

METHODOLOGICAL CONCLUSIONS

Without elaboration, let us merely observe that the study reported here demonstrates concretely the feasibility and power of an approach to analysis that actively works the gamut from high-resolution, entity-level, man-in-the-loop simulation on the one extreme, to exploratory analysis with fast-running desktop models on the other.[5] One of our principal objectives in undertaking this work was to accomplish such a demonstration. When such analytic work is used to inform and exploit empirical work, including large-scale field experiments, a great deal can be learned about the phenomenology of future military operations—including the risks associated with them and how to mitigate those risks.

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[4]By far the most effective way to use PEM in understanding the situational and tactical effects is by working with PEM interactively. A single “exploratory analysis” session, possible even by a nonprogrammer, can be quite illuminating. Much is lost when we abstract results for the print media.

[5]For our prior discussions on the matter advocating such an approach, see Davis, Gompert, Hillestad, and Johnson (1998) and Davis, Bigelow, and McEver (1999). For theory underlying the modeling issues, see Davis and Bigelow (1998).

Table 8.2

Kills per F-16 Sortie with Sensor-Fused Weapons for 0, 10, and 16 Minutes from Last Update[a]

Dispersal/Terrain	Open	Mixed	Primitive Mixed
No Timing Error			
Very tight	8.5	8.4	4
Dispersed	6.1	6.0	2.7
Very dispersed	2.7	2.6	1.0
10 Minute Errors			
Very tight	8.5	8.4	4.0
Dispersed	2	2.1	1.2
Very dispersed	0.95	0.95	0.65
16 Minute Errors			
Very tight	8.5	8.4	4
Dispersed	0.9	0.86	0.54
Very dispersed	0.36	0.36	0.25

Definitions: Very tight: 50 meters per AFV, 100 AFVs per packet; Dispersed: 100 meters per AFV, 10 AFVs per packet; Very dispersed: 200 meters per AFV, 5 AFVs per packet. Open: 12 km open-area mean widths; Mixed: 3 km open-area mean widths; Primitive: 1 km open-area mean widths.

[a]These figures assume a factor of 0.25 for the fractional error in estimating maneuver speed along the road. Actual time errors in projecting the arrival of targets in an open area are then four times the numbers shown in the tables.