SUMMARY

OBJECTIVES

This report describes how various situational and tactical factors—which are usually treated only in complex models, if at all—can influence the effectiveness of long-range precision weapons in interdicting a moving armored column. The variables we consider are characteristics of the C^4ISR system—i.e., the system for Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance. The variables treated include: time from last update; missile and weapon characteristics, such as footprint; maneuver pattern of the advancing column, such as vehicle spacing; aggregate terrain features, such as open versus mixed terrain of different types; and employment tactics for long-range fires, such as firing in salvos with the missiles offset in time and space.

We also describe a stochastic personal computer model (PEM, which stands for PGM effectiveness modifier) to explore these effects systematically.[1] PEM was motivated by and has been calibrated to results of high-resolution simulation at the entity level. It is quite useful for scaling calculations, although absolute weapon-effectiveness levels also depend on classified details that we have not modeled, such as the acoustic environment, which is a function of the larger march configuration and terrain in the general area of targeting. Finally, we also describe a simplified and deterministic "Repro model"

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[1]PEM is programmed in Analytica®, a visual-modeling system for Macintosh and PC computers, which is available from Lumina Decision Systems.

called RPEM and provide reductionist results in a set of tables. Such simplified representations of the phenomena may prove directly useful in higher level campaign models such as JICM and the emerging JWARS.

CONCLUSIONS

General

The factors mentioned above have very large implications for the effectiveness of long-range precision fires, as measured by kills per two-missile salvo or per aircraft sortie. If a "standard" case for such fires is attacking a column of armored vehicles separated on average by no more than 50 meters and traveling across terrain that offers no concealment (e.g., the desert), then effectiveness can be quite high—either with small-footprint air-delivered munitions such as sensor-fused weapons (SFWs) or with long-range missiles such as ATACMS/BAT. However, under other assumptions regarding standoff range, C^4ISR capabilities, dispersal, and terrain, effectiveness can drop by two orders of magnitude.

The various factors interact in complex ways that cannot be modeled as a mere product of, for example, a terrain adjustment, a Red dispersion adjustment, a C^4ISR adjustment, and so on. The sensitivity of outcome to one factor depends strongly on other factors, so linear sensitivity analysis around some baseline can be misleading. For this and other reasons related to input uncertainty, we have emphasized an "exploratory analysis approach" that assesses relative effectiveness across a wide range of cases in which the factors are varied simultaneously.

Specific Observations

Dispersal During Maneuver. The Red maneuver pattern, which can reflect a passive Red countermeasure against the Blue attack, interacts with several of the other factors. If Blue's timing of weapon delivery is good, changing the Red maneuver pattern—e.g., by increasing the spacing between armored fighting vehicles (AFVs)—usually has a much greater effect in canopied terrain with small open areas than in terrain with large ones. Moreover, in such terrain, a weapon such as ATACMS/BAT with a large footprint loses much of its advantage over a weapon, such as sensor-fused weapons, with a small footprint.

C^{4}ISR Factors. Depending on the other factors, the time since last update[2] can range from very important to irrelevant. If Red maneuvers in long columns of densely spaced vehicles, then kills per salvo or sortie are independent of the time since last update. But if Red has a more complex maneuver pattern, Blue must time his shots so that they arrive in open areas when the Red packet does. 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 with weapons intended for multiple kills, even if the time since last update is zero. This is especially true if the weapon has a long "descent time"—i.e. a long time between when its submunitions acquire targets and when they reach the ground.

If the Red formation maintains strict discipline and moves with constant speed, then a small time since last update will pay large dividends for "normal" maneuver tactics and open terrain. But if Red is more dispersed and deliberately changes speeds frequently, effectiveness of area weapons in mixed terrain can be quite low even if time from last update is rather small. In that case the payoff is much higher for less expensive one-on-one weapons, which may be delivered from short range by aircraft or from the short-range fire of maneuver forces.

The ability to discriminate between live and dead targets is significant if multiple shots are fired into the same area without leaving time for dead targets to stop and cool, or if a single weapon can kill a large number of vehicles. It is an open issue, however, whether adding such discrimination capabilities will prove cost-effective.

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[2]The time of last update is the time between when a weapon is last directed to impact at a particular time and place and when impact occurs. It is an important attribute of the C^{4}ISR-weapon-system combination. It can be shortened by: minimizing command-related delays, time of flight, and processing within the C^{4}ISR system; providing target updates to missiles in flight; and combinations.

Force-Employment Tactics. Offsetting a salvo's missiles in time usually 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 small-footprint area weapons delivered from aircraft is quite important because dead-target effects (failure to discriminate) would otherwise greatly reduce effectiveness.

Summary Quantitative Results

Tables S.1 and S.2 summarize results of PEM runs in estimating the effectiveness of ATACMS/BAT and F-16/SFW weapon combinations 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 effectiveness numbers would also depend on both classified and unclassified 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 within Tables S.1 and S.2. As can be seen by comparing the top-left and bottom-right figures, we should expect a factor of roughly 100 in weapon effectiveness as a function of these three variables. Comparable tables can be generated by PEM for other weapon types.

One important caution here is that readers should not attempt simple cost-effectiveness comparisons using PEM alone—even with classified input data rather than the illustrative figures we have used. As reported in an ongoing RAND study on interdiction for the Joint Staff (Ochmanek et al., unpublished), analysis strongly argues for *mixes* of different weapon types because if the United States has such mixes, and if the weapons are all of high quality, a would-be invader will have much less incentive to disperse (see also McEver, Davis, and Bigelow, forthcoming). Further, as discussed elsewhere (Matsumura, Steeb, et al., 1999), analysis also suggests that mixes of long-range fires and light-mechanized maneuver forces would have major advantages over long-range fires alone, especially in complex terrain and when the invader employs anticipated tactical and technical countermeasures.

Table S.1

Sensitivity of Kills per ATACMS/BAT Salvo to Timing Errors, Dispersion, and Type Terrain[a,b,c]

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

[a]Absolute values also depend on other situational details not provided here to avoid classification.

[b]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. "Mixed terrain" also assumes canopies.

[c]The timing error is the difference in minutes between when the targeted packet is centered in the open area and the time of arrival of the weapon. If the error in estimating the packet's movement rate along the road is 25% (after accounting for winding roads, random movements, and deliberate changes of speed as a countermeasure), then the timing errors shown would be one-fourth the "time from last update."

Methodological Conclusions

This study demonstrates concretely the feasibility and power of a multiresolution 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

Table S.2

Sensitivity of Kills per F-16 Sortie with 4 SFWs to Timing Errors, Dispersion, and Type Terrain

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

NOTES: See Table S.1.

models on the other.[3] 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. As discussed elsewhere (Davis, Bigelow, and McEver, 1999), we strongly recommend that the Department of Defense and U.S. Joint Forces Command adopt such an approach in its work on next-generation forces, doctrine, and related joint field experiments.

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[3]For prior discussions, see Davis, Gompert, Hillestad, and Johnson (1998) and Davis, Bigelow, and McEver (1999). For underlying theory, see Davis and Bigelow (1998).