TOP-LEVEL VIEW

Figure 2.1 describes the top-level flow of EXHALT. Figure 2.1 should be seen as describing data flow at a particular time step—i.e., it applies at an arbitrary snapshot in time. Arrows show the direction of data flow; dashed arrows indicate where data from one node at the previous time step is used as input to another node in the present time step (i.e., feedback). It is implicit that each variable’s update during the time step may depend on its own values at previous times. Subsequent figures (which are copied directly from the computer screen) include what appear to be double-headed arrows. These are actually a combination of a solid forward arrow and a mostly obscured dashed feedback arrow. We shall describe Figure 2.1 briefly and then walk through each of the modules shown in somewhat more detail.

The Update Blue Shooters module takes information regarding Blue’s forward-deployed aircraft and missiles, his warning time (tactical and strategic), deployment rates (for various types of shooters), losses taken in the previous period, effectiveness status as of the previous period, and deployment or theater capacity limits to calculate the number of “shooters” of each type Blue has available in the theater at a given time. How Blue uses these shooters is determined in another module.1

1The variable Shooters, like most other variables in EXHALT, is described mathematically by an array—in this case, a simple vector with a component for each type of shooter (e.g., F-15E/F, the Army Tactical Missile System [ATACMS], AH-64). Another
The **Blue Effectiveness** module uses inputs for Blue’s C4ISR capabilities, kill and sortie rates for Blue’s various shooter types, and some possible strategies Red and Blue might use (e.g., Red may use dash-and-hide tactics, and Blue may concentrate attacks on Red’s leading-edge armored fighting vehicles [AFVs]) to determine the effectiveness of Blue’s sorties against Red’s armor. The tactics and effects are discussed in more detail later.

The **Blue Losses** module calculates the shooter losses that Blue takes during the halt campaign, using Blue shooter and sortie tallies, and a loss-per-sortie or -shot function that declines over time as Red’s air defenses are degraded.

The **Blue Command and Control** (C2) module then allocates some fraction of each type of Blue’s available shooters to anti-armor missions, withholding some for other missions, such as strategic attacks; it may also withhold some of Blue’s shooters if Blue is still concerned
about strong Red air defenses, or if C4ISR assets are not yet adequately effective. To accomplish this, the Blue C2 module can employ two optional “decision agents” (so called because they represent, i.e., act as agents for, human decisionmakers), which are described in more detail in subsequent sections.

In the **Attack Red** module, Blue’s shooters attack Red’s armor. The Attack Red module calculates Red’s losses and the number of AFVs remaining in Red’s advance. Finally, the **Update Red** module updates Red’s position and numbers, making use of Red’s speed of advance. The next wave of Blue attacks then begins, and the model updates Blue’s numbers for losses taken in the last wave and new deployments that may have arrived.

Let us now describe each of the above modules in somewhat more detail. Even more detail is provided within the model itself. Indeed, we anticipate that—except for one reading of this overview report—users of EXHALT will rely almost entirely upon the model’s self-documenting features.

**UPDATE BLUE SHOOTERS**

This module, the top-level diagram for which is shown in Figure 2.2, calculates the number of shooters of each type present in the theater through the halt campaign.\(^2\) Initial shooters, arrival rates, deployment caps, and theater capacities are read from the Blue Shooter Inputs matrix (described in Appendix A). Arrival rates and theater and deployment shooter limits can further be affected by a possible Red threat of the use of weapons of mass destruction (WMD), Red mining of waterways, or the ability of Red (and his allies) to constrain Blue’s ability to use bases convenient to the theater. These factors, along with the tactical warning time, are used to calculate the

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\(^2\) The conventions for this and all similar drawings are as follows: Deterministic inputs are indicated by rectangular or trapezoidal nodes (shown in later diagrams). Inputs determined by random draw are indicated by oval nodes. Outputs are indicated by hexagonal nodes (these will appear in subsequent figures). Single-variable nodes are indicated by oblongs, while modules containing two or more nodes are indicated by oblongs with darker edges and bold lettering. Italic lettering indicates that the node shown is being copied here for convenience (as an “alias”), but is actually located in another module. Tiny arrows to the immediate left or right of a node indicate influences from or on nodes outside the current diagram.
number of shooters of each type present in the theater when the Red advance begins (D-Day). During each step, new shooters arriving in the theater are added (if theater air base capacity has not been reached), and the losses taken from the last step by Blue from Red’s air defenses are subtracted. The resulting vector of available Blue shooters, indexed by shooter type, is then passed on to the C2 module, in which some portion of the shooters will be allocated to anti-armor missions.³

Figure 2.2 identifies two input nodes, those for tactical warning time and for the presence of WMD or mining, as probabilistic input variables.⁴ These nodes take advantage of Analytica’s ability to assign

³In fact, this information is also passed to the Blue Losses module, as indicated by Figure 2.1.

⁴EXHALT is a stochastic model, but we reserve the term stochastic for instances in which we are referring to processes that are random within a given real or simulated war, as distinct from parameters that may have well-defined values for a given war but
input values drawn from probability tables or distributions specified by the user. Importantly, this feature allows us to use EXHALT to examine some of the real effects of uncertainty in the scenario space of the early halt problem.

BLUE EFFECTIVENESS

This module calculates the effectiveness of Blue’s attacks on Red’s AFVs. The top-level Analytica diagram for this module is shown as Figure 2.3. It includes several time-dependent multipliers to Blue’s nominal effectiveness. An “Effectiveness Multiplier Source?” switch allows users either to input the aggregate multiplier to Blue’s effectiveness (indexed by shooter type) or to have it calculated from higher-resolution factors. Each of these factors is merely driven by parameters in EXHALT, but the parameter ranges and uncertainty distributions used should be based on higher-resolution analysis and empirical work (Davis, Bigelow, and McEver, 1999). In any case, the factors treated here are as follows:

- **Attack-mode effects due to Blue’s attack strategy.** Blue can attack with either a leading-edge or in-depth strategy. The leading-edge strategy (Ochmanek et al., 1998) allows “rollbacks” in that, if Blue is able to completely shatter the forward x km of a column on a given day, the column’s effective advance will be reduced by x km/day. If Blue has enough interdiction capability, x may be greater than the nominal column speed, V, in which case the advance will be rolled back by (x–V) km/day.5 Further, since leading-edge attacks are concentrated on forward units, Blue can stop an entire unit (i.e., remove that unit from the advance) by destroying some fraction of that unit, specified as the "Unit

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5The term rollback is not rigorous, since, in principle, a portion of the force in the “rollback area” could still take cover (“go to ground”) and mount opposition, rather than flee.
Break Point." We assume that Blue suffers an effectiveness degrade in these leading-edge attacks, since concentrating attacks at Red’s front is more difficult than allowing attacks throughout Red’s advance. Blue’s in-depth strategy suffers no such degrade but likewise has none of the other advantages of the leading-edge strategy; in particular, the advance continues to move at a constant rate until the “halt fraction” of his forces has been killed, and the advancing units suffer no “unit dissolution” effects, since Blue’s attacks are distributed throughout the advance. The leading-edge strategy’s advantages, which can be dramatic, diminish quickly as the number of axes of advance—or the number of columns per axis—increases (Davis and Carrillo,

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6This effect is like the larger “Halt fraction” effect, by which the entire advance falls apart after some fraction of the advance is destroyed. Use of the Unit Break Point assumes that a unit will fall apart after some fraction of its component armor is destroyed, removing all of that unit’s AFVs from the advance. (The Unit Break Point can be set to 1 if users wish to employ the leading-edge rollback effect, but not this “unit dissolution” effect.) The effect of the Unit Break Point appears in the Attack Red module.
1997), although such a multiaxis advance might also be slower if the extra roads were poorer than the main road (Ochmanek et al., 1998).

- **Gain competence factors.** Unless given adequate tactical warning time or exceptional training to allow Blue to exercise his C⁴ISR personnel and assets, Blue will not begin the campaign with his C⁴ISR assets fully effective. This module calculates a time-dependent multiplier to Blue effectiveness due to this factor. With time, Blue’s competence in command and control matters approaches its nominal level.

- **Early C⁴ISR effects.** Blue experiences time-dependent multipliers to his effectiveness that are related to the early deployability and survivability of his C⁴ISR system. Blue’s effectiveness is degraded early, depending on how effective Blue’s C⁴ISR assets can be in the face of Red’s air defenses.

- **C⁴ISR quality effects.** These effects are represented parametrically in the C⁴ISR Engagement Factor, which accounts for such effects as the ability of Blue to provide targets to his shooters quickly; his ability to see through foliage to acquire and hit targets; and the saturation point of his reconnaissance, surveillance, targeting, and acquisition (RSTA) system. This factor has qualitative values like “Base” or “Enhanced” that represent different levels of Blue C⁴ISR system capability. Characteristics of the several levels are based loosely on results from high-resolution studies of potential capabilities.

- **Dash effects.** As a tactic to counter Blue’s attacks, Red can—in theaters that have appropriate hiding places—adopt “dash” tactics, in which he concentrates his movement during relatively small parts of the day, then goes into hiding the rest of the day (Davis and Carrillo, 1997). Red is constrained in doing so by his ability to coordinate such movement, the terrain, and other factors. Blue can react to this strategy by concentrating his attacks during Red’s movement periods or by having systems capable of finding and attacking hiding Red AFVs. Although this is currently a parametric calculation to make a point, the module could be replaced in the future by a more phenomenological representation based on higher-resolution analysis. For example, one
response to this Red countermeasure would be Blue combat air patrol stations.\(^7\)

- **WMD and mining effects.** If Red can threaten to use chemical, biological, or even nuclear weapons or to mine critical waterways, Blue’s ability to deploy to the theater and attack can be slowed. This module highlights this factor (although the effects of WMD are actually distributed across different parts of the model).\(^8\)

- **Terrain and dispersion effects.** The presence of mixed terrain, in which Red is only vulnerable when in open areas of the terrain, reduces the effectiveness of Blue’s attacks. This effect is complicated by the fact that Red AFVs may travel in platoon and company packets, meaning that Red’s presence in open areas is not uniform. This module allows users to input a shooter-dependent multiplier to represent this effect. A more detailed model, Reproduction of the Precision Engagement Model (RPEM), is provided “on-line” in the Terrain/Dispersion Effects module to assist users in arriving at reasonable multipliers. RPEM is derived from a higher-resolution model developed from entity-level simulation data.\(^9\)

These multipliers are combined with the nominal values of kills per sortie or shot and sorties per day for each shooter type to determine the effectiveness of each of Blue’s shooter types at any point in the campaign.\(^{10}\) These effectivenesses are then reexpressed as multiples

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\(^7\)Colleague Glenn A. Kent has studied some possibilities in this regard.

\(^8\)The threat of Red’s use of WMD and/or mining affects (in EXHALT) Blue’s sortie rates, arrival rates, and theater shooter capacity.

\(^9\)This factor is calibrated to a more detailed stochastic model (Precision Engagement Model [PEM]), which in turn was motivated by and calibrated to results of high-resolution simulation (Davis, Bigelow, and McEver, forthcoming). RPEM is not connected to EXHALT but can be used to generate estimates of terrain-dispersion effects for various weapon systems in a given scenario, so that users can insert reasonable multipliers into the terrain-dispersion effects input vector.

\(^{10}\)In the current version of EXHALT, the nominal value of kills per sortie or shot of a given platform does not depend explicitly on weapon loading or the spacing of vehicles. To use EXHALT in a weapon-mix study, however, one would need to include these dependences explicitly. See Ochmanek et al. (unpublished manuscript) for a game-theoretic discussion of why Blue having a mix of weapons could limit the value of Red’s obvious tactic of dispersing vehicles to reduce the effectiveness of Blue’s area
of a “standard shooter’s” effectiveness.\(^{11}\) This information is passed to the Blue C2 module, in which the shooters-available vector is converted to a simple number of equivalent shooters (i.e., a scalar rather than a vector) and assigned to anti-armor attacks. This is convenient, for reasons discussed later, but does not reduce generality.

**BLUE C2**

EXHALT contains a “commander model” (Figure 2.4), which takes the shooter vector produced in the “Update Blue Shooters” module and—accounting for withheld sorties due to the wait time, attacks on strategic and other targets, and the decision to withhold missiles until early effectiveness degrades have been mitigated—generates the number of “equivalent shooters” that will attack Red’s armored targets.

The C2 module also includes decision models dealing with strategy and tactics. These are simple “agent” models that represent human commanders faced with imperfect information and difficult trade-offs. The missile-launch decision is a rather trivial example of such a decision agent, one allowing Blue to withhold the launching of his missiles until C4ISR and other factors are sufficient to ensure a threshold level of effectiveness, rather than simply scripting the missile launch for some predetermined time that would be inappropriate if other parameters, such as Competence Time from Warning or C4ISR System, were changed.

A more intricate example of a decision agent is the optional wait-time decision module. In this, a Blue commander estimates various campaign outcomes as a function of his choices and, based on those estimates, chooses a “wait time” (how long Blue will fly at a reduced rate because of relatively robust Red air defenses at the beginning of the campaign), that best matches his criteria for success. This involves trading off likely Red penetration distance against likely losses of Blue’s air forces.\(^{12}\) Once the wait-time decision agent selects

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\(^{11}\)The default, which is easy to change, is that the F-15E is a standard shooter.

\(^{12}\)Since this is a unique and fairly complex feature of the EXHALT model, it is described in some detail in Appendix B.
the best wait time, any wait-time sortie effects and set-asides for attacks on strategic targets (i.e., targets other than Red AFVs) are accounted for.

Each shooter type in the resulting vector is then converted into equivalent shooters by multiplying it by its relative effectiveness (in terms of kills per shooter-day) compared to the effectiveness of the “standard” shooter. The components of the vector are then summed to produce a scalar value of equivalent shooters that will attack Red AFVs during the current step. This step is mathematically unnecessary and introduces no further approximations, but, in keeping with the multiresolution design of EXHALT, it permits (without requiring) users to simplify the model by scripting the attacks of equivalent shooters, as is sometimes convenient.

Figure 2.4—Top Level of the “Blue C2” (or “Blue Commander”) Module

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13As described in Chapter Three, the wait-time decision agent can be switched off, in which case a user-specified input value for the wait time will be used.
**BLUE LOSSES**

This module (Figure 2.5) calculates the losses that Blue takes during the Halt campaign. Each shooter type has, as an input, an initial loss rate. This rate is defined as the probability that a shooter of that type will be lost to Red air defenses or other factors during a given sortie. Each shooter’s loss rate declines exponentially at a rate based on the SEAD time. Since the Halt point is considered to be the point at which Red’s advance collapses, Red’s air defenses are consid-

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14In the baseline version of the model, only aircraft losses are accounted for, but one can enter loss rates for missile batteries as well; those would be loss rates per shot rather than per sortie. They might be the result of counterfire or special operations forces.
ered to collapse there as well and become inactive once halt is achieved.

The module calculates the number of sorties flown in a given time step by each shooter type and then calculates the losses to each shooter type based on that type’s loss rate at that time. Shooters are assumed to have carried out their attacks before they are lost, and the losses are subtracted from the shooters available for the next step’s attacks.

To provide a single number as a measure of overall losses, part of the module converts the vector of lost shooters to a single number of equivalent shooters. However, the full vector of losses by shooter type is used in determining the number of shooters available. Should such detail not be needed, users may switch off the Blue losses calculation (which also turns off the wait-time decision agent, since one of the agent’s decision criteria is Blue losses).

**ATTACK RED**

This module (Figure 2.6) calculates the number of Red armored vehicles that Blue kills in a given time step by multiplying the number of equivalent Blue shooters attacking Red armored targets by the kills per standard shooter-day of the equivalent Blue shooter, and then adjusting for the length of the time stamp.

If Blue uses the “leading-edge” attack strategy, additional Red armored vehicles are considered to be disabled by Blue’s attacks. As mentioned in the explanation of the leading-edge attack strategy in the “Blue Effectiveness” section, we reason that Blue’s leading-edge attacks are concentrated on a particular segment of the Red advance and that each unit within that segment has a “break point” beyond which the remainder of the attacked units cannot continue to function. The “Unit Break Point” is specified as an input, and once that fraction is destroyed, the remaining AFVs in that unit are disabled and removed from the advance.\(^\text{15}\) In EXHALT, the sum of AFVs disabled in this way and those directly killed are referred to as “AFVs Stopped.”

\(^\text{15}\) We assume that Blue is able to allocate and target his sorties so that he destroys each Red unit with the minimum force possible.
Once Blue’s potential to destroy or disable Red AFVs in the current time step is determined, this potential is compared to the number of Red AFVs remaining, to ensure the Blue cannot stop more AFVs than remain.

**UPDATE RED**

This module (Figure 2.7) updates the position of Red’s advance as a result of this period’s movement (if any) and attacks. If the Overall Halt Fraction of Red’s initial armored force has not been destroyed or disabled, Red will advance at his base movement rate (adjusted for the length of the time step), minus any “rollback” that may have occurred as a result of Blue’s attacks. Rollback calculations are detailed in the “Calculate Length of Column Stopped by Blue Attacks” module within the “Calculate Red Movement and Position” module.

If Red’s position places him at the objective, his penetration will stop there, but Red armored vehicles will begin to accumulate at the
objective at a rate determined by the base movement rate, the rollback, the spacing, and the number of axes and columns along which Red advances. Red forces will accumulate at the objective until all remaining Red forces arrive there; all remaining Red forces have been destroyed or disabled; or Blue’s rollback of Red is sufficient to push him back from the objective (in which case, the Red armor at the objective remains there).

If more than the Overall Halt Fraction of Red’s initial armored force has been stopped, Red’s base movement rate drops to zero, and the only movement that takes place is due to Blue’s rollback of Red forces (although, in general, the distance measurement most of interest is the distance of maximum Red penetration, which will occur while Red has a positive base movement rate).

Figure 2.7—Top Level of the “Update Red” Module
The module also keeps track of the cumulative number of Red armored vehicles stopped and destroyed, as well as marking how many total Red armored vehicles were stopped and destroyed at the end of the simulation. The user can also specify an “Interim Point,” some distance along Red’s advance, and observe Red’s strength, in terms of number and fraction of AFVs remaining. This is valuable for the purpose of considering possible defense lines by small Blue ground forces (including allies). Rather than actually modeling close combat, one can simply observe the strength that would be needed at the defense line, when Red arrives there, to achieve the desired force ratio.