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D. Gantz, G. Blais, S. Solomon (eds.)

QUICKSCREEN

Timothy C. Hawkins and G. Frank Thompson
The BDM Corporation
7915 Jones Branch Drive
McLean, Virginia 22102

ABSTRACT

This paper describes a corps-level combat simulation developed by The BDM Corporation for the US ARMY. The simulation will be referred to here as Quickscreen, although its official Army designation is being changed to CORBAN (Corps Battle Analysis). Quickscreen can represent the activities of hundreds of individual units of battalion size and smaller in the context of a large-scale conflict and can treat all major elements of the AirLand Battle. Quickscreen was specifically designed to operate on a microcomputer and is currently operational on a Motorola-68000-based microcomputer system. The sophistication of Quickscreen's representation of command and control, and its ability to run on a microcomputer, put it on the cutting edge of combat simulation technology. Quickscreen has already seen extensive and significant application by the Army's Deep Attack Program Office.

INTRODUCTION

Quickscreen is a corps-scope, battalion-resolution combat simulation developed by The BDM Corporation for the US Army. Its simulated conflict can include hundreds of individually represented units, each having a number of individually represented assets (e.g., weapons). Each unit carries on its own perception, combat, decision, and movement processes under control of orders developed and input by the analyst, or developed automatically in the simulation. Each unit has an ability to "think" for itself and to move freely about the battlefield in pursuit of its mission. Headquarters units can develop their own "plans," including orders to coordinate the actions of their subordinates. Quickscreen can simulate an entire battle in a single run, or simulate it in time slices. When time slices are used, forces and orders can be manually altered between the runs. The major output items produced by Quickscreen are battlefield snapshots, decision traces, and attrition statistics. Each battlefield snapshot indicates the locations, status, and current activities of all units in the simulated battle at a particular time. A decision trace records significant decisions made by all units over a particular interval in the battle. Attrition statistics indicate the particular types of assets, and the numbers, destroyed by each represented weapon type over a particular interval. Postprocessors exist to display some of these outputs in graphical form.

Quickscreen was developed over a period of approximately two and a half years, and was specifically designed to run on a microcomputer. Currently, Quickscreen is operational on both a Motorola-68000-based system with approximately 1.2 Megabytes of RAM, and on a VAX 11/725 system. Run time for Quickscreen is highly scenario-dependent. However, even for the most complex scenarios yet considered (including hundreds of units and very complicated plans), the simulation on the 68000-based system has exceeded a 2:1 ratio of simulated time to processing time. Many smaller scenarios of interest run much faster. The Quickscreen software includes approximately 25000 lines of FORTRAN code, along with small amounts of PASCAL and assembly language code.

Quickscreen is at the leading edge of combat modeling technology due to the power and flexibility of its command and control model, and due to the fact that it provides this capability in a microcomputer environment. Quickscreen is unique in its ability to generate complex operation plans from simple orders and "operation templates." The "automated" command and control model in Quickscreen greatly decreases the burden on the analyst by relieving him of the task of generating detailed orders for large numbers of units. However, if for some reason he wants "hands on" control of some portion of the simulated force, Quickscreen also provides that option.

Quickscreen allows representation of all major elements of the AirLand Battle, including conventional combat, air support, air defense, logistics, engineer operations, electronic warfare, and nuclear weapons. While the model represents maneuver units at battalion resolution, other units of company, battery, or smaller size can also be individually represented. The powerful command and control model allows the simulated battle to "automatically" develop in a realistic fashion from the analyst's high-level plan for each side, and specified bodies of doctrine and tactics appropriate for each type of unit represented on each side. The combination of the level of resolution provided and the sophistication of the command and control model makes Quickscreen suitable for analysis of many major issues in the AirLand Battle. It is ideal, for example, for the evaluation of alternative weapons mixes, force mixes, tactics, or doctrine. Its availability on a microcomputer and relatively rapid execution make it ideal for "what if?" analyses in general, since many alternatives can be explored relatively cheaply.

Quickscreen has reduced the cost of running a complex corps-level combat simulation to the point of affordability for small, resource-constrained study groups. The time, manpower, and computer costs required to operate Quickscreen are considerably less than those required to operate previous simulations of comparable scope and resolution. As a result, tasks that in the past would have required up to dozens of analysts with access to a mainframe computer can now be performed by a small group of analysts using a microcomputer.

The next two sections of this paper will describe the manner in which Quickscreen models corps-level battle. The first of these sections will provide a general description of the way in which individual units are represented, and will also outline the manner in which major processes such as perception, combat, and movement are modeled. The next section will provide a somewhat more detailed description of the manner in which Quickscreen models command and control. A short following section will discuss applications of Quickscreen to date.

GENERAL DESCRIPTION OF THE QUICKSCREEN SIMULATION

OVERVIEW

Quickscreen is a "unit-centered" combat simulation. It determines the outcome of a large-scale engagement by simulating the activities and interactions of a large number of individually represented units on each side of the conflict. Scenarios for applications to date have included up to 700 individual units. Types of units represented have included maneuver and artillery units, headquarters, logistics points and convoys, ground-based and airborne sensors, airbases, fixed-wing and helicopter sorties, and air defense units. In general, represented units are of battalion size or smaller. Each occurence in the simulated conflict is directly attributable to the activity of some particular unit. At any given point in the simulation, each unit has a currently effective order which specifies a particular mission to be accomplished. Each unit also has a particular set of "assets" (weapons, supplies, etc.) on hand. A unit's attempts to employ its assets to accomplish its mission are constrained by the unit's own state, by the local environment in which it operates, and by the activities of other units, both enemy and friendly, in its vicinity. Over the course of the simulated battle, then, some units succeed in their missions, and others fail. Together, these many individual small-scale successes and failures determine the manner in which the large-scale simulated battle develops.

Quickscreen is a time-stepped simulation. In applications to date, a fixed time step of 10 minutes has been employed, although the step size can be varied from run to run, if desired. In each time step, each represented unit is processed in turn. Currently, all units from one side are processed, and then all units from the other. Processing for each unit involves simulation of its execution of a set of processes appropriate to its particular type. Certain fundamental processes -- e.g., perception, combat, decision, and movement -- are executed by units of all types. Other processes, such as operation planning and logistics support, are carried out only by units of particular types -- in these cases, by headquarters and logistics units, respectively. Through the perception process, a unit assesses its own current state and develops a list of potential targets for engagement in the combat process. Through the decision process, the unit determines if its current perceived situation calls for a transition in behavior based on either the unit's current orders or on the doctrine under which it is currently operating. Through the combat process, the unit determines how its available firepower should be allocated, and actually employs this firepower to inflict attrition and suppression on the assets of opposing units. Through the movement process, the unit determines how best to move toward its current objective, and actually moves with the speed dictated by its current circumstances.

REPRESENTATION OF THE CONFLICT ENVIRONMENT

Elements of the conflict environment which Quickscreen was designed to treat include weather, day/night, and terrain features, both natural and man-made. However, in applications to date, only the representation of terrain features has actually been used, and the presentation here will be limited to a discussion of terrain.

Representation of terrain features in Quickscreen is closely tied to the "hex" coordinate system used in the simulation for specifying unit locations and objectives. At its finest resolution, this multi-level coordinate system divides the battlefield into regular hexagons, or level-0 hexes, each 3.57 kilometers across (side to side). Groups of seven of these level-0 hexes constitute level-1 hexes, as depicted in Figure 1. While it can be seen that a level-1 hex is not actually hexagonal in shape, it is approximated by a hexagon 9.45 kilometers across, and with its faces rotated with respect to the corresponding faces of the level-0 hexes by approximately 19.1 degrees. Similarly, groups of seven level-1 hexes constitute level-2 hexes, which are approximated by hexagons 25 kilometers side to side, and with their faces rotated by another 19.1 degrees. The entire Quickscreen coordinate system can cover the area of one level-7 hex created by repeated groupings of seven hexes at each lower level. This area is approximated by a hexagon 3241 kilometers across. Quickscreen permits unit locations, and objectives, to be specified at any level from 0 through 6. In applications to date, for example, ground units move among level-0 hexes, while air units typically move among level-2 hexes. Terrain features, however, are associated exclusively with level-0 hexes.

Each level-0 hex in an area through which units might actually move during the course of the simulated conflict must have terrain features defined for it. (Terrain can remain undefined for other, "unused" hexes.) The initial terrain features for each hex include levels of forestation, ruggedness, and urban buildup. Four levels are possible for each of these features. Also, a level of road connectivity to each adjacent hex must be specified, as must a level of river barrier on the boundary with each adjacent hex. Four levels are also possible for each of these features, with the lowest level indicating effective absence of the considered feature. All of these terrain features have an effect on the speed at which a unit can move through a hex, and may also affect a unit's assessment of the desirability of moving into the hex at all. The forestation, ruggedness, and buildup levels also affect the probability of line-of-sight within a hex, and thus the effective number of targets available for engagement in the combat process.

The features described thus far characterize the state of a hex at the start of the conflict. Quickscreen provides mechanisms whereby such features can be effectively altered during the course of the conflict, and new features can be added as well. The employment of a nuclear weapon in a particular hex might, for example, alter the terrain by blowing down forest, cratering roads, and adding nuclear contamination. It might also destroy the bridge across a particular hex side which is implied by the presence of both road connectivity and a river. Similarly, engineer activity in a hex can affect

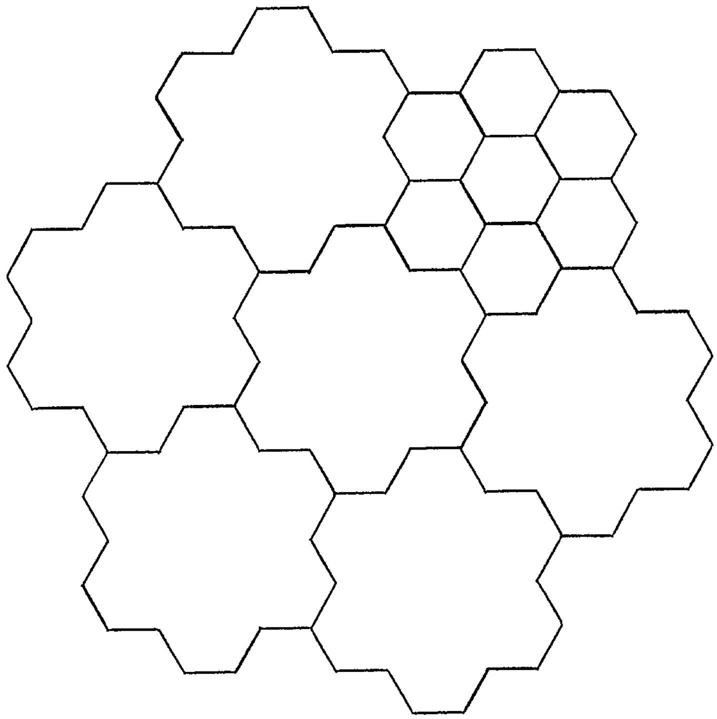

Figure 1: A Level-2 Hex, Its Constituent Level-1 Hexes and the Constituent Level-0 Hexes of One of These

terrain features. For example, a minefield can be created on a hex side, or a bridge constructed across a previously unbridged river. Such alterations to the initial terrain can affect the movement and combat processes of units in much the same way as original features.

REPRESENTATION OF UNITS

Quickscreen's representation of each unit in the simulated conflict includes the following basic elements: unit type, assets currently held, location, command relationships, perceptions, and orders. Each of these elements will be discussed in turn.

UNIT TYPES. Each unit is identified as one of a set of analyst-defined basic unit types. Example unit types used in applications to date include "maneuver battalion," "headquarters," "helicopter sortie," and "ground sensor." Each unit type definition provides basic information on the order in which the four major common processes (perception, combat, decision, and movement) are to be executed for units of that type, and also which "special" processes such units may execute (e.g., logistics or airbase operations). Each unit type definition also indicates particular "engagement modes" (e.g., direct fire, anti-air, counter-battery) which can be used by units of that type, and particular modes to which such units are themselves vulnerable. It further indicates the level of hexes among which units of that type (initially) move.

ASSETS. A separate list of assets is maintained for each unit. This list indicates the types of assets currently held by the unit, the number of each type held, and the number of each type currently suppressed by enemy fire. In general, some of the assets held by each unit are weapons of various types. These can be used in the combat process to attrit and suppress the assets of other units. Other assets held can include ammunition and POL, with the former affecting the unit's combat readiness, and the latter affecting its mobility. Personnel can also be treated as a unit asset, with combat capability being degraded in the absence of sufficient crew to man available weapons. Examples of other types of equipment which can be treated as assets include communication equipment, radars, jammers, and trucks. Any or all of a unit's assets are, in general, subject to attack by enemy units. Enemy fire can destroy a unit's assets or just temporarily suppress them. It can also transform assets into corresponding damaged assets, which then require repair to transform them back to the original usable assets. The total set of assets on hand for a given unit is used to determine an overall effectiveness level for the unit. If this effectiveness drops below a certain threshold (associated with the unit's current operation), then the unit itself is dissolved. Thus, a unit is dependent on its assets for its very existence. The characteristics of each asset type represented in a Quickscreen scenario are defined by the analyst. Quickscreen applications to date have represented as many as 200 different asset types in a single scenario.

UNIT LOCATION. Quickscreen represents each unit's location in terms of the multi-level hex coordinate system introduced earlier. Each unit (at least potentially) moves among the hexes at some particular level of this system. At any given time, then, the unit is located in some particular hex at that level, and is facing in the direction of one of the sides of that hex. A unit which is not currently moving is assumed, for all purposes, to be located at the center of its current hex. A unit which is moving is assumed, for certain purposes, to be located on a line segment joining the centers of the two adjacent hexes between which it is moving. Fractional progress along this line segment is updated by the movement process, and the unit's current hex is updated when half or more of the segment has been traversed. For perception and decision processes, only the hex in which a unit is located is significant. For combat and movement processes, however, the more precise unit location derived from consideration of fractional progess between hex centers is used.

To permit a single unit to occupy multiple hexes simultaneously, Quickscreen employs "markers" to designate separately located fractions of the unit. Such a marker can "occupy" a hex in the same way as can a normal unit. It can be detected and engaged by other units independent of the remainder of its unit. It can also engage enemy units, but does so in conjunction with the rest of its unit. Markers do not move independently. Instead, they are positioned about the location of the "real" unit in accordance with specifications associated with the unit's current operation and assigned sector width. Markers allow a small force to cover a large sector width without leaving gaps (unoccupied hexes) in the line.

COMMAND RELATIONSHIPS. Each unit in Quickscreen has a single immediate superior to which it reports and from which it may receive orders. A unit can also have one or more subordinate units. Command relationships need not remain static over the course of the simulated conflict. A unit may be detached from its current superior and re-attached to another at any point in the conflict. Such actions occur based on specifications in unit orders and plans. For example, a plan may call for an artillery unit to be re-attached when one command passes through another to move to the front.

UNIT PERCEPTIONS. Each unit generates perceptions of its own state and perceptions of other units in its vicinity, including enemy units which it has the potential to engage. The central element of a unit's self-perception is a set of "situation features," each of which is evaluated as either present or absent. Some of these features have a significance which is fixed for all units and for all scenarios. The significance of others is determined by the analyst, and may vary from unit to unit and run to run. Examples of the "fixed" situation features include "unit facing a dangerous force ratio," "unit has threat on left flank," "unit at geographical objective," and "unit POL level below prescribed level." Any of the situation features, fixed or analyst-defined, can serve as input to the unit's decision process. The most important element of a unit's perception of other units around it is its (potential) targets list. This indicates the locations, types, and strengths of units which are candidates for engagement. This targets list is the primary input to the unit's combat process.

A unit with a plan also maintains perceptions of the states of those units (generally its subordinates) which are explicitly referred to, either "by name" or by characteristics, in its plan. For subordinates, it obtains these perceptions by processing status reports from the units themselves. These reports include the situation features perceived by the individual subordinates themselves. Information on non-subordinate units may be obtained through the direct perception capabilities of the unit with the plan. This information may include, for example, unit locations, strengths, and current operations. These perceptions of units in the plan can serve as input to those portions of the decision process relating to the plan.

UNIT ORDERS. At any point in the simulated conflict, each unit's behavior is directed by its currently effective order, which affects all of the unit's processes. The most fundamental piece of information in the order specifies a particular "Operation Reaction System" (ORS). The ORS can best be thought of as a body of doctrine which defines the context for interpreting the order, and which indicates ways in which the unit can effectively alter the order, if necessary, to deal with its particular circumstances. A part of the definition of each ORS is a set of operations which may be executed by units employing that ORS. Different ORSs are generally employed for similar unit types from opposing sides, as well as for different types from the same side. Examples of ORSs are "BLUE maneuver battalion," "RED maneuver battalion," "Blue artillery," and "RED administration/logistics." Examples of operations in the set for a BLUE maneuver battalion ORS are "prepared defense," "hasty attack," "assembly area," and "march to contact." Quickscreen applications to date have employed as many as 20 different ORSs in a single scenario, and as many as 20 different operations within a single ORS.

Along with the ORS, each order specifies a mission and an operation. Each of these specifications refers to one of the set of operations associated with the specified ORS. In general, the two are the same, at least initially, but they can differ. The mission specification controls the unit's "mental" (decision) processes -- i.e., the way it "thinks." The operation specification controls the unit's physical processes -- e.g., the disposition of various assets within the unit, its perception capabilities, and its maximum speed. The analyst-supplied definition for each operation in an ORS defines parameters for both mental and physical processes. When mission and operation differ, "mental" parameters are taken from one operation description and "physical" parameters, from another.

In addition to the mission and operation specification which tell a unit what to do, each order also includes information on where in particular to do it. Each order specifies either a geographical (hex) objective or a unit-relative objective. An objective of the latter type indicates that the unit should attempt to position itself at a specified offset from a particular unit -- e.g., 10 kilometers behind. The order also specifies an axis for the unit, which controls its facing, and a sector width, which governs its lateral disposition, and may determine the number of markers employed for the unit.

The presentation to this point has implied that each unit has just one order effective at any particular time. Actually, a unit can have multiple, simultaneously effective orders, each controlling a different process, or processes. Headquarters units, in fact, typically have two orders in effect at all times. One of these orders controls the activities of the headquarters and headquarters company as a "physical" entity. This order controls the movement of the headquarters itself on the battlefield, and controls its own limited perception and combat capabilities. The second order controls the operation planning and control functions of the headquarters. Provided with this order, or automatically developed from it, is the plan which the headquarters uses to coordinate the activities of its subordinates and accomplish the mission of its command as a whole. The mission, operation, objective, axis, and sector width specified in this order are for the entire command, not just the headquarters unit itself.

In addition to its currently effective orders, each unit can have an arbitrary number of contingency orders, each to be made effective only under specified circumstances. A unit's decision process ensures that each contingency order is activated if and when the appropriate circumstances arise.

REPRESENTATION OF PROCESSES

In each time step of the simulated conflict, each unit, in turn, executes a set of basic processes appropriate to its unit type and to its currently effective orders. Certain processes are executed by all units, including the perception, combat, decision, and movement processes referred to previously. Additional minor processes also executed by all units include recovery (from combat effects) and communication. A number of other "special" processes are executed only by particular unit types. Headquarters units, for example, can engage in a planning process to transform simple orders into elaborate plans. They can also engage in a support allocation process in which they handle requests from subordinates for various forms of support and see that each type of support is actually allocated in accordance with priorities dictated by the current plan. Logistics units engage in their own special process in which, within the limits of their materiel stocks and available transport assets, they create convoy units to deliver requested supplies and equipment to other units. Similarly, airbase units and helicopter base units engage in their own processes in which they create and launch sorties to support other units. Quickscreen's modeling of such "special" processes will not be addressed further in this paper, except for the planning process. The remainder of this section will first discuss the order in which the common processes are executed by each unit in each time step. Then, Quicksreen's modeling of the perception, combat, movement, recovery, and communication processes will be discussed. A more detailed discussion of the decision process will follow in the next section.

PROCESS SEQUENCING. In a typical time step, a typical unit executes the four major common processes in the following order: perception, combat, decision, movement. Thus, the typical unit first looks, then shoots, then thinks, and finally moves in each time step. Since the perception process drives each of the other three, it is natural that it be executed first. Furthermore, since the results of the perception process derive from the hex in which the unit is located, and the movement process can take the unit out of that hex, it is natural that movement be last. As for the combat and decision processes, each is, to a degree, capable of driving the other. The combat process can change certain situation features considered in the decision process. Also, the decision process can change the unit's operation, with major impacts on combat. However, in typical scenarios, a typical unit does not make a significant decision in most time steps. Even when it decides to change operations, this change can only occur after an analyst-specified time delay, so the change may have no impact at all in the current time step. Consequently, the decision process is executed after combat for typical units. The alternative process sequence -- in which a unit looks, then thinks, then shoots, and finally moves -- can be employed for units of selected types. This sequence is typically used for air units. Orders for such a unit frequently call for it to fly out to a specified target area and then change to an attack operation to employ its weapons. Such a unit moves and attacks rapidly, and may have the potential for attacking and then exiting the target area in a single time step. Allowing such a unit to execute its decision process before combat makes it possible for the unit to arrive in its target hex, recognize its arrival, change to an attack operation (without delay), and execute the attack -- all in a single time step. Use of the typical-unit sequence would not allow this, since the change to attack operation would come after combat processing.

The two process sequences just presented each indicate only one execution of each process. In fact, in proper circumstances a unit may repeat a process or processes, in a single time step. For example, whenever a unit makes a decision which immediately changes its operation, the unit re-executes the perception process, since its results are heavily driven by the operation. The change of operation may, for example, change the engagement modes which the unit can employ, and thus change the types of units it can engage. As a result, the targets list generated by the second execution of the perception process may differ markedly from that generated by the first. A more extreme example of process repetition occurs for "fast mover" units -- i.e., units which move into more than one new hex in a single time step. For such a unit, the full sequence of processes is repeated for each hex which it completely traverses in a time step. For example, the unit executes the combat process in each of these hexes, but with its effective firepower being reduced to account for the fact that it actually spends just a fraction of the time step in each hex. If no special measures were taken, a unit completely traversing a hex in a single time step would not itself be subject to attack while in that hex, since it would never be in that hex during combat processing for enemy units. To avoid this situation, fast movers cause special (out of turn) execution of the combat process for enemy units in each hex which they completely traverse in a time step.

THE PERCEPTION PROCESS. The basic purpose of the perception process of each unit is to assess its own condition and to gather information on the positions, status, and activities of other units around it. The unit uses this information in its combat, decision, and movement processes. In some cases, it also transmits some of the information to other units. Two basic categories of perception activity may be distinguished, one performed by all units and the other, only by units having plans. The first category, general perception, establishes the presence or absence of certain situation features for the unit, builds a targets list, and develops a "map" indicating the positions of nearby units, to be used in the movement process. This activity starts "from scratch" in each time step; its results are not carried forward from step to step. A by-product of this activity is the placement of markers for the perceiving unit. The second category of activity, role-filling perception, seeks to identify units which can "fill roles" in the perceiving unit's plan. This involves seeking detectable units which match criteria specified in role definitions -- e.g., an artillery unit in a certain general area. Results of role-filling perception do carry forward to succeeding time steps.

A portion of the general perception process requires consideration of only the perceiving unit itself. This includes determination of the unit's current level of effectiveness and of whether it is at its current objective. The unit is assessed as "fully effective," "marginally effective," or "ineffective" by comparing its current strength (derived from its assets) to a base strength. The unit's effectiveness and position-relative-to-objective are expressed as situation features for use by the decision process. If the unit's strength is found to be too low even for "ineffective," then the unit is dissolved and removed from the simulation. A special exception is made for headquarters units, however, since the plans they maintain are crucial to the proper development of the simulated conflict. No matter how low the effectiveness of a headquarters unit, it is never permanently removed unless an associated alternate headquarters is available to take over its plan. If no such alternate is available, an effectively dead headquarters is temporarily removed from the simulation, but is assumed to have been reconstituted after a suitable time has passed, and is therefore revived.

The portion of the general perception process directed to detecting other units involves use of an appropriate "search pattern" for the perceiving unit. A search pattern defines the set of hexes in which a unit "using" that pattern can potentially detect other units. For example, a pattern may indicate that units can be detected in the perceiving unit's own hex and in the three adjacent hexes in front of it. A search pattern can also identify hexes in which a unit employing it should place markers, and indicate the fraction of the total force to be placed in each such hex. The search pattern to be used by a unit at a given time is determined by the unit's type and by its current operation and sector width. Different search patterns are generally used for different unit types, and for units of the same type but from opposing sides or executing different operations. All search patterns are analyst-defined. Applications to date have employed as many as 50 different search patterns in a single run.

Search patterns are grouped into classes. Each unit type may have an associated search class, as may each operation. If a unit's type has an associated search class, then the unit always uses a pattern from that class. Otherwise, the unit uses a pattern from the class associated with its current operation. The particular pattern selected from a class depends on the perceiving unit's current sector width. Associated with each search class is a table of probabilities indicating the likelihood of detecting various types of units at various ranges.

Once the appropriate search pattern has been identified, the perception process involves "laying down" this pattern in accord with the perceiving unit's location and facing, and then checking for other units in each hex in the pattern. For each unit found, a Monte Carlo draw is made against a detection probability appropriate to the hex and unit type in order to determine whether or not the unit is detected. If so, then its position is recorded on the local "map" being developed. If the detected unit is an enemy, it may be added to the targets list as well. The search class specifies a limit on the size of the targets list, and the search pattern limits permissable engagement modes against units in each hex in the pattern. If the list is not already full, and the perceiving unit can employ some engagement mode allowed for the hex, then the unit is added to the targets list. Each detected unit, friendly or enemy, is considered in the perceiving unit's computation of a local force ratio. This ratio considers the positions as well as the strengths of detected units, weighting the units in each hex by parameters specified in the search pattern definition. The level of threat on the unit's left and right flanks is also evaluated using threat weighting factors from the search pattern. The computed force ratio and threat levels are compared to thresholds specified for the perceiving unit's current operation. These comparisons establish the presence or absence of threat-related situation features considered by the decision process.

THE COMBAT PROCESS. The purpose of the combat process executed by a given unit is to allow that unit to employ its weapons to attrit and/or suppress the assets of other units. It does not allow other units to return fire. Their opportunities come when they themselves, in their turns, execute the combat process. In general, a unit's combat process is driven by the targets list produced by its perception process, and if this list is empty, then no weapons are employed. A unit with targets seeks to employ each of its available weapon types, in turn. When employing direct-fire weapons, (e.g., tanks), a unit allocates fire against selected asset types within the target units. When employing indirect-fire weapons (e.g., artillery), a unit just allocates fire against particular target units, not individual asset types. In this case, any asset of a targeted unit is equally likely to be hit. When employing an area weapon (e.g., nuclear weapon), a unit does not allocate the "fire" at all. In this case, any unit within the effects zone of the weapon is affected. Area weapons are the only ones which can be employed even when the target list is empty, since they can be targeted against a location rather than a unit. The treatment of area weapons in the combat process differs substantially from those for direct- and indirect-fire weapons, and will not be discussed further in this paper. The following presentation will describe the treatment of direct-fire weapons. The major differences for indirect fire revolve around the targeting of units rather than asset types within units.

The first step in employment of a particular weapon type is to determine the effective number of weapons available -- i.e., the number which can actually fire in the current time step. This is derived from the number on hand and the number suppressed, and from the availability of required ammunition and crew (assets). The next step is to consider all of the targets against which fire from the considered weapons could be allocated, and to determine the effects each would suffer if it received all of the fire. In the process of running through the possible targets, a relative priority is established for each. When all targets have been considered, these relative priorities are used to determine the actual allocation of fire. The calculated effects for each target are then reduced consistent with the fire actually allocated, and those effects are then applied. If any assets are attritted, then certain "dependent assets" may be attritted also. A certain amount of ammunition, POL, and crew can be specified to be lost with each asset type. Also, certain types of assets can be declared to be "mounted" on another asset type for a particular operation. If an asset is destroyed which has others mounted on it, those mounted are also destroyed. If any assets are suppressed, then an overall level of suppression for the target unit as a whole is also updated.

The total set of possible targets to be considered for each weapon includes each asset type for each unit (or marker) in the targets list. For example, three units in the targets list, each with the same four asset types, provide twelve distinct targets. Some potential targets may not in fact be engageable by a particular weapon type. Similar to unit types, asset (weapon) types have particular engagement modes in which they can be employed, and particular engagement modes to which they are vulnerable. Also, the operation of the unit executing combat limits the modes which can be employed. For a target to be engageable, there must be a common engagement mode which is allowed by the type and operation of the shooting unit, the type of the weapon, the location of the target unit relative to the shooting unit -- and which is also among those to which both the target unit type and asset type are vulnerable. If no such match exists, the target is skipped for the considered weapon, though it may be engageable by another.

For an engageable target, the first step toward determining the effects of engagement is to establish the number of individual weapons of the considered type which would actually have an asset of the considered target type to fire at -- i.e., the number having target asset(s) in range and visible. This number is determined on the basis of "disposition patterns" for the shooting and target units, and of line-of-sight probabilities appropriate to the terrain. A disposition pattern is associated with each operation. This pattern characterizes the distribution of assets within a unit executing that operation. It does so by specifying distributions in depth for various asset categories for a number of "views" of the unit -- e.g., the view from the front, or the view from the right flank. Line-of-sight probability is determined based on the levels of ruggedness, forestation, and urban buildup in the target's hex and on the degree to which the target unit's current operation allows it to take advantage of the terrain.

The number of firing weapons is adjusted to eliminate those without targets, and the number of individual rounds which could be fired in the time step is then determined based on the considered weapon type's specified firing rate against the basic target type represented by the target asset. The number of target assets which could be killed and/or suppressed is then determined based on specified per-shot probabilities for the considered weapon versus the basic target type, with numerous adjustments for factors including, among others, the hardness of the target asset type relative to its basic target type, and the operations of the two units involved. The actual allocation of fire among the considered targets is determined on the basis of allocation specifications in the targets list (derived from the search pattern), in the weapon description, and in the description of the shooting unit's operation.

THE MOVEMENT PROCESS. The purpose of the movement process executed by a given unit is to determine the direction in which the unit should be moving, and to move it in that direction at a speed consistent with the local terrain and with its current status and operation. In general, a unit already moving selects a new direction for movement only when it completes its current move by reaching the center of the hex it is entering. However, in certain circumstances -- e.g., on receipt of a new order -- a unit will reconsider its direction before completing the move in progress. Whenever a unit selects a direction for movement, it can make any of seven possible decisions -- stay in the current hex (a null move), or move into one of the six hexes immediately adjacent.

A unit's determination of the proper direction to move at a particular time is based on its current operation and objective, on the local terrain (including highways), and on the positions of other units in the vicinity, as indicated by the "map" developed in its perception process. The description of each operation specifies many parameters affecting the choice of movement direction. Some of these limit movement selection by establishing minimum or maximum levels for certain terrain features in hexes or hex sides to be traversed. For example, an operation can require a minimum level of roads in the direction to be traveled, or a maximum roughness level for a hex to be entered, or a maximum level of river to be crossed in the absence of a bridge. An operation can also specify a maximum acceptable massing of friendly forces in a hex to be entered, and a maximum acceptable enemy force in such a hex. An operation description also specifies weighting factors for use in computing "scores" for comparing the movement alternatives not ruled out by such limits. Each of the alternatives to be compared is first scored on how well it achieves each of five goals -- making speed toward the objective, providing cover, avoiding massing, avoiding enemy forces, and avoiding contaminated terrain. The individual scores are then combined by using weighting factors indicating the relative importance of each of the five goals in the current operation. The alternative with the highest combined score is then selected.

If a unit's current operation so specifies, it will look ahead more than one move (hex) in order to score movement alternatives. The number of hexes which the unit looks ahead is specified in the operation description. When such lookahead is employed, the score for a given (1-hex) move alternative is the best of all scores which could be achieved by beginning with that move. Use of lookahead substantially lessens the chances that a unit will have to back up as a result of moving into a hex from which there is no exit in the general direction of its objective.

In general, the speed at which a unit can move is determined by the operation it is executing, the force ratio it is facing, the terrain over which it is traveling, and whether it is moving on- or off-road. The unit's operation defines a limit to the speed which can be made against the force ratio faced, and also determines whether or not the unit utilizes available roads. If the unit does use roads, then the speed is also limited by the level of roads present and by the ruggedness level of the hex traversed. If the unit travels off-road, then its speed is limited by the levels of ruggedness, forestation, and buildup in the hex. If the unit is crossing a river off-road, this limit is adjusted downward to account for a crossing delay based on the level of river. In general, a unit's speed is the minimum of the limit determined by operation and opposition and the limit determined by terrain. Speed can, however, also be limited by the presence of contamination in a hex or by a shortage of POL. Also, certain unit types (air units) are not affected by terrain at all.

THE RECOVERY PROCESS. The purpose of the recovery process executed by a given unit is to allow the unit's individual assets, and the unit as a whole, to recover from suppression inflicted by enemy units. It also allows a unit which is below the "fully effective" level to recover toward full effectiveness, provided that it is not currently in contact with the enemy and is not currently moving. For each asset type held by the unit, the number of those assets currrently suppressed is reduced by a fraction specified in the asset type description. Suppression for the unit as a whole is reduced by a fraction specified for the unit's current operation. The unit's effectiveness level derives from the ratio of its current strength to its base strength. Current strength decreases as a unit suffers attrition, while base strength does not, so the unit's effectiveness level drops. However, when a unit is away from the enemy and not moving, its base strength is adjusted downward toward its current strength at a rate specified for the unit's operation. Thus, a marginally effective or ineffective unit which is held out of action eventually regains full effectiveness, even though it is not as strong as it was originally.

THE COMMUNICATION PROCESS. The purpose of the communication process is to allow information to be passed from one unit to another with a delay appropriate to the nature of the information and the circumstances of the two units involved. Quickscreen does not model individual real-world messages, but rather general information flows. The types of "messages" (information flows) treated in Quickscreen include, for example, orders, status reports, and target data. Communication may occur with or without delay, at the analyst's option. If delay is to be imposed, the delay for a particular message is determined by the unit types of the sender and receiver, by the message type, and by the current levels of suppression of the "communication equipment" asset of each of the units. This communication asset is subject to "attack" and suppression by enemy jammer assets. If no such asset is included in a particular scenario, then the overall levels of suppression for the communicating units are used instead.

COMMAND AND CONTROL MODELING IN QUICKSCREEN

Two major aspects of Quickscreen's modeling of command and control will be discussed here -- the planning process and the decision process. Others -- e.g., the support allocation process -- will not be addressed. In the interest of clarity, many special cases are ignored in the presentation to follow, especially for the planning process.

THE PLANNING PROCESS

The purpose of the planning process is to take a simple order specifying the mission and objective for an entire command, and to develop from it a plan for directing, supporting, and coordinating the activities of the individual units making up that command. This process is executed only by headquarters units, which must employ their subordinate units to actually carry out their missions. In applications to date, the planning process has been used by division, brigade, and regimental headquarters units.

Central to the planning process is the notion of an "operation template." An operation template is a generic description of a particular type of operation. It characterizes the operation in terms of a number of "roles" to be filled by the units of a command executing the operation, a number of phases through which the operation can develop, and sets of orders to indicate what a unit filling each role is to do in each phase. It defines various "contingencies" which determine when certain situation features are to be considered present, or which define when phase transitions are to occur. It also includes priorities for the allocation of resources among roles over the course of the operation. The template includes no references to "real" units or locations, only references to roles and coordinates on an abstract planning grid. All orders included are template orders, which must be "detailed" (filled in with specific objectives) before they can be executed. The planning process combines the generic information from a template with particular information about the planning unit and its command to generate a particular plan referring to real units and locations. It "lays down" the planning grid on real terrain, assigns real units to fill the template's roles, details the template orders, and disseminates them to the proper units for execution.

The particular operation template to be used to plan from a given order is determined by the ORS and mission specifications in the order. These together identify a particular operation. Specified in the operation's template are requirements for the number of subordinates, overall strength, and overall effectiveness of any command to execute that operation. If the planning unit fails to meet any of these criteria, then the operation is deemed inappropriate. Quickscreen then allows for consideration of a specified alternative operation. In fact, an arbitrary number of alternatives can be checked, one after another, until an appropriate one is found, or all possibilities are exhausted. In the latter case, the planning proceeds for the last alternative regardless, operating in a "last resort" mode in which criteria are relaxed throughout the planning process.

The first step in actually making a plan is to "lay down" the planning grid. This involves positioning, orienting, and scaling the grid in accord with the location of the planning unit and with the objective, axis, and sector width specified in the order. The result is a coordinate transformation which allows the abstract locations and objectives in the template to the translated into "real" hex locations. For offensive operations, for example, the grid is positioned with its origin at the center of mass of the command. The grid is oriented and scaled such that its (0,1) point coincides with the objective specified in the order, and the distance between its (-1,0) and (1,0) points is equal to the specified sector width.

Next, attention is turned to the roles to be filled. For planning purposes, three basic role types are distinguished -- subordinate roles, other-unit roles, and terrain roles. Subordinate roles are those to which one or more particular subordinates are to be assigned. Other-unit roles are to be filled by the role-filling perception process. Terrain roles are not to be filled at all, but are a way of defining locations with particular terrain characteristics (e.g., barriers or chokepoints). The template specifies a location for each role. The specification may be in planning grid coordinates, or it may be in terms of offsets from the location of another role. The location may also include terrain specifications which direct a search within a given area for a location meeting specified criteria (e.g., a location traversed by major roads).

In an initial pass through the roles, an attempt is made to associate a "real" (hex) location with each role. For a location requiring particular terrain characteristics, if no such terrain exists, then the attempt fails. In such a case, no role referencing that location can be filled. For each subordinate role indicated to be "critical," an attempt is made to fill that role in the first pass. Filling a role involves determining which available condidate units satisfy the requirements for the role, and assigning the closest one(s) to the role. Any subordinate not already assigned is a candidate, as is the planning headquarters unit itself, which can fill a role in its own plan. The requirements for a given role might relate, for example, to unit type, strength, and effectiveness level. If no candidate satisfies the requirements for a role, then it cannot be filled.

If one or more critical roles cannot be filled, then the normal planning process is considered to have failed. If no untried alternative operation remains, then the planning process goes to a "last resort" mode with relaxed criteria, and the planning continues regardless. Once all critical roles have been disposed of, other subordinate roles are considered, and each remaining unassigned candidate is assigned to fill one of these if possible. Any candidate still not assigned a role is then put into a default role, if one is specified for the operation.

When role-filling has been completed, a roles list is built for the developed plan. This indicates the correspondence between roles and subordinates, and provides a repository for the information to be maintained on each role over the course of the operation. Attention is then turned to the orders associated with each filled role. The template should include at least one order for the unit(s) filling each role, and this order may have a number of associated contingency orders as well. Before these orders can be sent to a unit filling the role, the first order must be detailed. The final step of the planning process is to put the initial phase of the newly planned operation into effect for the planning unit, and to disseminate the detailed orders to the subordinates. The planning unit will, in general, send an order to itself to control its own "physical" functions within the new operation.

THE DECISION PROCESS

The primary purpose of the decision, or "thinking," process of a given unit is to recognize and respond to situations calling for changes to the order(s) governing its behavior. A secondary purpose is to send information to its superior and subordinates for use in their decision processes. The decision process effects transitions between orders, and between phases in a plan. It can also effect "automatic" (SOP) transitions of mission and/or operation within an order, while retaining other elements of the order unchanged. In conjunction with any of these changes, one or more "actions" can be executed.

A unit begins its decision process by gathering the information necessary to determine the transitions and/or actions, if any, currently called for. Some of this information comes from the unit's own perceptions, and some comes as messages from other units. The thinking unit first determines whether it has received a new order from its superior. If so, it replaces its corresponding old order with the new one. If the new order calls for a different operation than the old, the operation may not be changed immediately. If the analyst has specified a time delay for switching into the new operation, then the old operation is retained (in the new order) until that time has passed. If the new order is a headquarters order -- i.e., an order requiring a plan -- then if a plan is not already attached, the planning process is executed to develop one. If a unit has no new order, then it checks for a phase-change message from its superior. Such a message would indicate transition to a new phase in the superior's plan, which might in turn call for some corresponding transition by the thinking unit.

The unit next processes messages indicating the status of other units. Among these are status reports from subordinate units. Each such report provides all relevant data on the state of a particular unit at the time of the report. In particular, the report includes the reporting unit's situation flags, which indicate the particular situation features present and absent for the unit. If the reporting unit fills a role in the thinking unit's plan, then the report is used to update the status of that role in the plan. The thinking unit also processes any unit-elimination messages, each indicating the removal of a specified unit from the simulation. If an eliminated unit was filling a role in the thinking unit's plan, then that role is marked unfilled. The thinking unit also processes any "coordination" messages received from its superior or subordinates. Each such message specifies situation features to be considered present for the thinking unit. The message is used to set the corresponding situation flag(s), which may drive later stages of the decision process.

When all messages have been processed, the unit determines if a timer has expired for one of its orders, or for the current phase in its plan, assuming that it has one. Each order or phase can have a timer which expires at a fixed time, or at the end of a specified interval. There is a situation feature for "time expired for physical order" and one for "time expired for headquarters order or current phase in plan." If a timer has expired, then one of these situation features is recognized, and the corresponding flag is set.

There are certain situation features which can be recognized by all units. The timer-expired features are among these, as are features such a "unit at geographical objective" and "unit facing dangerous force ratio." The particular situation flags corresponding to these features are the same for every unit. Their significance is built into Quickscreen, which sets them automatically when the corresponding features are present. Many situation flags, however, have no fixed significance, and can be used by the analyst to represent arbitrary situation features of interest. They are set only when analyst-specified criteria are met. The criteria for setting these flags are expressed in the same form as those for transitioning between orders, phases, missions, or operations. In fact, a particular set of criteria, or "contingency," can be the condition for both a transition and an associated flag setting. However, some contingencies can be conditions for flag settings alone. A group of such contingencies can be associated with any plan, and with any mission. The next step in the thinking process involves determining whether any such contingencies associated with the plan (if any) and mission of the thinking unit are true, and, if so, setting the corresponding flags. The flags to be set can be the thinking unit's own, or they can be global flags. Alternatively, flags can be set for the unit's superior, or for each of its subordinates. In these cases, the settings are actually accomplished by means of a coordination message to each unit involved.

A contingency is defined in terms of required states for specified situation flags. In the simplest case, the definition is in terms of the thinking unit's own flags. For example, a contingency can be defined to be true if flags 0 and 4 are set, and flags 1 and 20 are not. Alternatives can also be allowed. For example, a contingency can be true if either flag 6 is set or if flag 12 is not. In general, a contingency definition can reflect any set of individual-flag requirements arbitrarily combined by "and" and "or." A contingency can also specify requirements for situation flags not belonging to the thinking unit itself. For example, requirements can be specified for any of the global situation flags. Contingencies to be recognized by a unit with a plan can specify requirements for the situation flags maintained for any role in the plan. For subordinate unit roles, the settings of these flags are determined by status reports. For other roles, they are set by the role-filling perception process. One of the flags checkable for each role is the "role filled" flag.

Once all flag-setting contingencies have been checked, the thinking unit turns to contingencies defining transition conditions. Each current order can define contingencies for transitions to new orders, and the current phase of a plan can define contingencies for transitions to other phases. Also, the operation description for the mission specified in an order can define contingencies for automatic transitions of mission and/or operation within that order. In general, transition contingencies are defined in the same manner as discussed above; however, one special contingency, not concerned with situation flags, can be specified as a condition for order or phase transitions. This is the "on order" contingency, which requires only that the superior's current phase match the phase specified in the prospective new order or phase. This can be used to change orders or phases in response to phase-change messages from above. If the thinking unit has multiple orders in effect, then it considers possible transitions associated with each of them in turn. For each effective order, possible transitions to a new order are considered first, then possible transitions to a new phase, and finally transitions to a new mission and/or operation within the current order. Only one such transition (for each effective order) can actually occur in a single time step.

If a transition is made to a new order, that order is treated just as though it had been received in a new-order message. If the new order is in template form, then it is "detailed" before being put into effect. If there is a transition to a new phase, then phase-change messages are sent to all subordinate units. If there is a transition to a new operation -- either as a result of changing orders or merely changing operations within a current order -- the actual operation change may be delayed as discussed before.

A transition of any of the considered types can have an associated "action" to be performed in conjunction with it. If a transition occurs which has such an associated action, that action is executed immediately. A particular action can involve any one, or a combination, of the following: setting situation flags for the thinking unit or its superior or subordinates, transferring assets to another unit, generating support requests, changing the hex level at which the thinking unit moves, generating a new objective, developing a new plan, deciding to reconsider movement direction, or removing the thinking unit from the simulation. Of course, if the thinking unit does remove itself, its decision process terminates immediately. Such a self-removal action is typically used to dissolve air sorties or convoys which have completed their tasks.

APPLICATIONS OF QUICKSCREEN

The most extensive and significant application of Quickscreen to date has been by a special US Army study group -- the Deep Attack Program Office (DAPO) -- formed under the auspices of the Deputy Chief of Staff, Operations, Plans, and Training. DAPO employed the simulation to evaluate the doctrine and tactics necessary to carry out various deep attack options in a European conflict. An evaluation of candidate simulations for possible use in the deep attack study indicated that only Quickscreen offered a sufficiently flexible and powerful representation of command and control. The simulation was employed over a period of approximately six months to evaluate many alternative scenarios in three different corps areas. Analyst reaction to the results has been extremely favorable, and experience has indicated that a small staff can indeed generate and analyze complex scenarios, with many variations, in a short period of time. An important by-product of the DAPO effort is a large data base which can be employed with little change in future studies.

Quickscreen has also been employed by DAPO for quick-turnaround evaluations of weapons effectiveness. It is currently being employed in a DNA-sponsored study of tactical nuclear conflict. It has also been installed for future use by analysts at V CORPS Headquarters.

TIMOTHY C. HAWKINS

Dr. Hawkins received the Ph.D. degree in Electrical Engineering from The Ohio State University in 1975. He is currently a Principal Staff Member of The BDM Corporation, where he has been employed for the past ten years and has participated in the development of a number of BDM's METRIC family of combat simulations. Dr. Hawkins has been associated with the Quickscreen program for the past year and is currently involved in designing and implementing enhancements to the simulation.

The BDM Corporation
7915 Jones Branch Drive
McLean, Virginia 22102
(703) 821-5000

G. FRANK THOMPSON

Mr. Thompson received the MBA degree in International Business from St. Louis University in 1977 and the MS degree in Management/Operations Research from the Naval Postgraduate School in 1978. Mr. Thompson served 26 years as an officer in the US Army before joining The BDM Corporation in 1982, where he is now a Staff Member and Associate Manager. Mr. Thompson served as the Deputy Program Manager for BDM's support of the Army's Deep Attack Program Office in their use of Quickscreen.

The BDM Corporation
7915 Jones Branch Drive
McLean, Virginia 22102
(703) 821-5000