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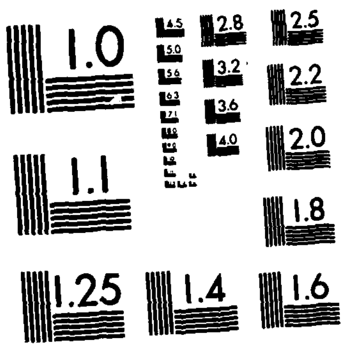
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UNICORN
(VERSION III)
METHODOLOGY

Science Applications Incorporated

SAI-76-048-DEN

UNICORN
(VERSION III)
METHODOLOGY

TECHNICAL MEMORANDUM

by

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ABSTRACT

This Technical Memorandum provides a macro-level description of the methodology implemented in UNICORN, an optimal weapon allocation computer model. The memorandum provides a discussion of the key UNICORN concepts and, where appropriate, the mathematical development of certain concepts used in the model. This document is intended for use in conjunction with the UNICORN (Version III) User's Manual, SAI-76-047-DEN.

A complete summary of the mathematics of the optimal weapon allocation methodology may be found in Selected Mathematical Programming Techniques for Force Allocation Problems, SAI-74-017-DEN.

INTRODUCTION

This technical memorandum will provide a macro-level description of the methodology implemented in UNICORN. The approach here will strive to provide a more in-depth discussion of key concepts than is found in the current UNICORN User's Manual (reference 1). However, this document will not attempt to provide system level documentation of the UNICORN computer code implementation.

The discussion includes a brief model overview including capabilities and limitations, some background material and a description of key concepts.

Model Overview

UNICORN is a force evaluation tool which is capable of considering a variety of issues relating to the capabilities of a user-specified arsenal. It simultaneously considers nuclear, chemical and conventional weapon alternative choices in optimally assigning weapons to a scenario target array. Each weapon and target is described by a set of user-specified values. The scenario is specified in terms of a set of grid locations of weapons and targets. The targets may be of arbitrary size ranging from division or less through theater. Virtually any indirect fire weapon (aircraft are considered to be indirect fire weapons) can be modeled by the current UNICORN version.

The model optimally allocates all defined weapons while considering a variety of controls and parameters. Each weapon and target location can be explicitly defined, and the weapon to target range considered in determining weapon impact error estimates. The model can allocate nuclear, chemical and conventional weapons as a function of range, survivability estimates, weapon effectiveness, target acquisition capability, and various constraints. For nuclear attack of a particular target type, either a radiation or a blast criteria may be specified. Several different forms of constraining conditions may be imposed. The user has the option of specifying an upper limit for blast, nuclear radiation, and thermal radiation levels at several points. In addition to the damage limitation consideration, the model can guarantee a least cost allocation which achieves user-specified levels of firepower and mobility damage. User-specified levels of target damage in a number of user-defined target categories can also be guaranteed. A weapon effectiveness drawdown can be readily determined, including optimal weapon deployment. The program also considers the effects of rate of fire limitations caused by weapons systems rates of fire, target acquisition, tactical and strategic C^3, and weapon survivability estimates.

With UNICORN, it is possible to analyze the influence of such factors as opponent posture, target characteristics, weapon characteristics and force design limitations such as dollar costs or plutonium stockpile levels. Among the important variabilities are: air-to-ground deliverable indirect fire weapons, size of the battlefield, target acquisition and location uncertainty. Weapon variabilities include: yield, range dependent accuracy, reliabilitv, and for conventional weapons, number of ICM submunitions, lethal areas and reliabilities. Chemical weapons may be defined with similar variabilities.

The model includes an explicit consideration of area aircraft defenses for the targets, area SAM defenses and target associated terminal SAM defenses. A further capability allows the user to artificially impose constraints upon the weapon allocation which may portray other than purely weapon effectiveness considerations in weapon employment. For example, the effects of political considerations, or warfare escalation effects may be investigated through these controls.

In UNICORN III, air representations have been expanded to model the effects of TACAIR-unique capabilities such as armed reconnaissance missions and loiter time on station, and to include an auotmated aircraft loading model. Another modification allows the user the option of modeling target persistence time and weapon delay time as either fixed lengths of time or as random variables distributed in time. Additional modifications include a military collateral damage assessment capability and a misestimates capability.

The model uses generalized linear programming to efficiently enumerate all of the possible assignments of weapons to targets. Each possible assignment forms a column in a linear programming tableau. A column consists of an objective function entry, a number of weapons of a particular type, the target to be attacked, appropriate entries for escalation controls and collateral population damage, firepower and mobility expected kill, plus resource constraint information such as budget or plutonium constraints. The method of solution is an iterative process, with a small number of possible assignments considered at each step. The best subset of assignments at each step is chosen by a linear program. New assignments are generated and placed in the tableau based on the most recent linear program solution. The process ends when no new assignments can be made or when the potential improvement in the objective function value falls below a specified level. The objective function is a sum of values from concave nonlinear functions, each reflecting the expected damage of the particular weapon-target combination.

The principal limitation of the current model is its inability to explicitly and dynamically consider opponent responses in the allocation process. These, however, can be considered to some extent via planning estimates which are program inputs. The model also currently does not consider direct fire attrition to conventional troop units.

Model Capabilities

This section briefly describes the principal capabilities of the current UNICORN model. These are the following:

Optimal Allocations

UNICORN optimally allocates a set of nuclear/conventional/chemical indirect fire weapons against a target array so as to maximize the expected damage against the target structure subject to a variety of allocation controls specified by the user. The alocation considers tradeoffs between weapon systems, and limitations caused by weapon systems performance, information processing uncertainties, deployments, target vulnerability, target defenses, and user-defined allocation requirements.

Range-Dependent Considerations

Weapons and targets are deployed by the user on a two-dimensional grid which is sized by one input value for width and another for depth in each direction from a FEBA. Weapon system minimum and maximum range limitations are explicitly considered, as are range-dependent CEPs, target location uncertainties, and target acquisition capabilities.

Damage Assessment

Point or area targets can be considered for attack by conventional, chemical and nuclear weapons, and target defeat criteria (confidence, coverage) are user specified. Nuclear attack of linear targets may also be considered. The user can select from a variety of target damage mechanisms depending upon weapon class. Nuclear weapons may utilize blast, radiation, cratering or dominant effects. Chemical weapons may utilize incapacitation, degradation of personnel or contamination. Conventional weapons may utilize fragmentation, HEAT, and a variety of other mechanisms.

Target Acquisition

The model considers target location uncertainty, and a range-dependent target acquisition probability which is specified at a particular reference observation interval (hours). This information is used in determining the acquisition capability which exists at other times of interest to the user. Target acquisition prior to the allocation interval may be represented separately.

C^3 Modeling

The model considers the effects of tactical C^3 in calculations with specified weapon response times and target persistence times. Nuclear/chemical release delay and strategic C^3 effects are approximately considered by limiting the number of targets which can be attacked by these weapons to that number which would be expected to be acquired after release authority was obtained and implemented, and by the reduction of force capability to reflect losses during the delay.

Weapon Survivability

Weapon survivability is represented for each weapon type and location by a fraction surviving at beginning of problem time and by a loss rate from which survivors are calculated for other times of interest.

Rate of Fire Calculations

The model allows the user to specify a planning horizon time and compute the force capability during that time interval. This calculation considers weapon system rate of fire limitations, tactical and strategic C^3 effects, and mean time-dependent attrition and target acquisition capability estimates.

Defenses

UNICORN contains an air defense model utilizing area interceptors, area SAM defenses which must be suppressed as a part of the weapon allocation, target related terminal SAM defenses and user-specified target location penetration probabilities. Each of these may be activated in varying degrees by user control.

Allocation Controls

The model contains a wide variety of user-specified allocation controls. These include limitations on which types of weapons are eligible to attack a given target, maximum damage expectancies desired against each target and limitations on collateral blast, thermal and/or radiation damage at user-specified locations. The user can also require that a specified fraction of the firepower and/or mobility of the target structure be destroyed or attacked. Additionally, the user can specify each target type as being in one of up to ten different categories, and can specify allocation goals against the categories. Similarly, the user can specify each target location as being in one of up to ten different classifications (sub locations), and can specify allocation goals against the sub locations. The model also allows the user to consider the effects of limiting civilian casualties. This latter calculation is based on a user-specified density near each target. The user may enforce a variety of political considerations or investigate warfare escalation boundaries by specifying eligible weapon/target combinations or eligible nuclear yields by target.

Arsenal Design

The model allows the user to consider force structuring alternatives by optimally designing that force which satisfies the force objectives, but does not exceed user-specified limits on the total number of warheads, the nuclear reactor material stockpile and/or the dollar cost.

Military Collateral Damage Assessment

After an allocation has been optimized, UNICORN provides a capability to assess the collateral effects on the target array from the allocated weapons. If the user has taken advantage of the option for specifying multiple targets at a location, he may provide simple guidelines for use by algorithms which will redistribute the multiple targets and associate pertinent weapons with appropriate aimpoints for the distributed targets.

Misestimates in Planning Data

After an allocation has been optimized, UNICORN provides a capability for assessing the variation in damage which would be expected if pertinent planning values were in error. Multiple assessments may be calculated for the same allocation, permitting exploration of effects for a range of error or various combinations of errors.

Model Limitations

Principal limitations of the current model are the following:

- The model is basically one-sided, and considers estimates of opponent responses rather than dynamically calculating what might happen over time as a result of the allocation conducted to date.
- Expected value calculations are generally performed. However, in some cases (e.g., the confidence/coverage target defeat criteria), points on statistical distributions other than the mean value are considered. For damage due to blast/radiation effects, the weapon CEP is integrated over a normal impact distribution. No Monte Carlo techniques are used.
- Targets defined in the target array structure are considered to be independent for the purposes of generating allocations and assessing primary damage. Hence, the choice of how a "target" is defined by the user should be consistent with this assumption.
- A flat-earth calculation is currently used to compute weapon to target ranges.
- Direct fire attrition to troop units is not considered.

DISCUSSION

UNICORN originally was developed as a prototype model for use in a research effort to identify useful procedures in analyses of theater/tactical nuclear weapons issues. It developed in a series of phases, under sponsorship of the Office of the Assistance Secretary of Defense (Program Analysis and Evaluation), recently redesignated as Office of the Director, Planning and Evaluation, OSD. The initial work was begun in 1973 and was motivated by Department of Defense reassessments of U.S. theater/tactical nuclear force posture, its critical strengths and weaknesses, its composition and the associated relationships to evolving U.S. nuclear policy (reference 2).

The prototype model (reference 3) was recognized as likely to be useful for the June 1974 POM cycle, and hence a concentrated effort was made to extend the model to be suitable for issues to be addressed in the POM analysis. The resulting version (reference 4) was delivered to the OASD (PA&E) MULTICS computer facility in May 1974, in time for the POM analysis.

The current model has been the result of follow-on work performed under Contract DCA100-75-C-0002.

This work, which is scheduled to be completed in January 1977, is concentrated in the following areas:

- Misestimate assessments capability
- Military collateral damage assessments capability
- Probalistic treatment of weapon/target time response
- Improved modeling of air weapon capabilities and air loading calculations
- Input/output improvements, including capability to tabulate and plot results over multiple analytic cases
- General maintenance.

As a part of this contract, a separate non-MULTICS UNICORN was prepared and delivered to CCTC, and technical assistance has been provided to PA&E and CCTC analysts in the use of the model for on-going studies.

During the period of performance of the current contract, three issues surfaced at PA&E which resulted in the addition of contract funds and tasks to adapt UNICORN to meet them. These issues centered around new weapon modernization proposals (such as enhanced/suppressed radiation and earth penetrators), chemical stockpile review questions from Congress, and a renewed interest in the characteristics of theater nuclear forces suitable for second echelon interdiction. The tasks involved the development of special subroutines for the rapid improved calculation of the lethal offset from multiple nuclear environments (static and dynamic overpressure, rads tissue, rads silicon, and thermal pulse), the development of special subroutines for calculating the cratering effects of earth penetrators, the development of special subroutines for calculating the effects of chemical weapons against a variety of target types, and special assistance in the area of second echelon interdiction analysis. This document has been prepared as a means of providing a timely, in-depth discussion of the model resutling from this contract.

The general weapon allocation techniques incorporated in the model adapt the concepts of generalized lagrange multipliers and specifically column generation techniques similar to those found in aggregated strategic force tools such as the Arsenal Exchange Model (AEM). These techniques permit the solution of constrained weapon allocation problems of enormous complexity through the use of a linear programming tableau structure. The process is distinctly different from typical, "row oriented" linear program applications and is best viewed as an optimal procedure for combining independent columns, each representing a weapon to target assignment strategy. A complete exposition of these techniques can be found in references 11, 12 and 13.

FINDINGS AND CONCLUSIONS--THE UNICORN METHODOLOGY

This section discusses the central concepts utilized in UNICORN and describes the actual implementation approaches. The central concepts actually are composed of two distinct methodologic areas. One of these areas relates to the methods of specifying accuracies, uncertainties, target and weapon location, weapon availability and other variabilities relating to scenario specifics required to define an allocation problem. The second methodology area covers the UNICORN allocation process, which relates the concept of strategy generation to linear programming and results in a capability to guarantee optimal weapon to target assignments.

The UNICORN solution process should be viewed as consisting of three distinct, sequential steps, the first two relating to scenario definition, that is defining the allocation problem, while the third is the allocation process itself. The steps are

(1) Define spatial and temporal relationships.

(2) For those eligible weapon launch point, target location combinations define a damage expectancy for each level of weapon allocation.

(3) Find the optimal level for each weapon against each target, consistent with the constraint set.

This section will discuss first those key concepts related to scenario definition and conclude with the key concepts related to the weapon allocation process.

Key Concepts - Scenario Definition

The general area of "Scenario Definition" as utilized herein is intended to encompass a variety of functions. These functions are performed through user interaction with UNICORN to define a weapon allocation problem to the point that it is suitable for solution by a linear program allocation process. This includes defining the physical characteristics of weapons and targets, their spatial relationships and the capabilities of the weapons in attacking the targets.

Spatial Relationships and Physical Characteristics

Scenario Area: The user may define a rectangular "scenario area" which provides a reference system for weapon launch points and target locations. The area's dimensions are defined by variables for width and depth. Figure 1 is an example of such an area. The depth value defines a distance extending in each direction from a straight line "width" kilometers long. The area has a coordinate system superimposed with its origin on the left axis and centered. All distances are computed relative to this origin.

Weapon launch points and target locations are defined in a coded manner. Any location is defined relative to a rectangular grid mapping the width into 1000 units in the X direction, and the depth value into 1000 units on each side of the X axis. If the width and depth dimensions are equal, then a cartesian coordinate system results. In any other case, a unit in X is not equal to a unit in Y.

Each weapon or target location also requires that a value defining associated physical characteristics be stated. A typical weapon might be (figure 1)

-10.123456

where 10 defines a weapon type, 123/1000 defines a fractional proportion of the width value of displacement in the X direction and -456/1000 defines a fractional proportion of the depth value of displacement in the negative Y direction. In general this may be written $\pm$(type).(XXX/1000) (YYY/1000) with the sign defining Y displacement. Given a set of specified values of locations in the system, modification of the width and depth values results in a scaling effect as if the positions were plotted on a partially-stretched rubber sheet which is then stretched or compressed in either direction.

Each weapon or target type may be associated with a variety of locations. Each weapon type has associated characteristics, which are user-defined and assumed not to vary with time, such as accuracy versus range, minimum and maximum range limits, lethality class or type, and many others. Each target type similarly has characteristics assumed to be static such as target radius, a nominal "hardness" or vulnerability characteristic, a "value", user attack-type preference and others.

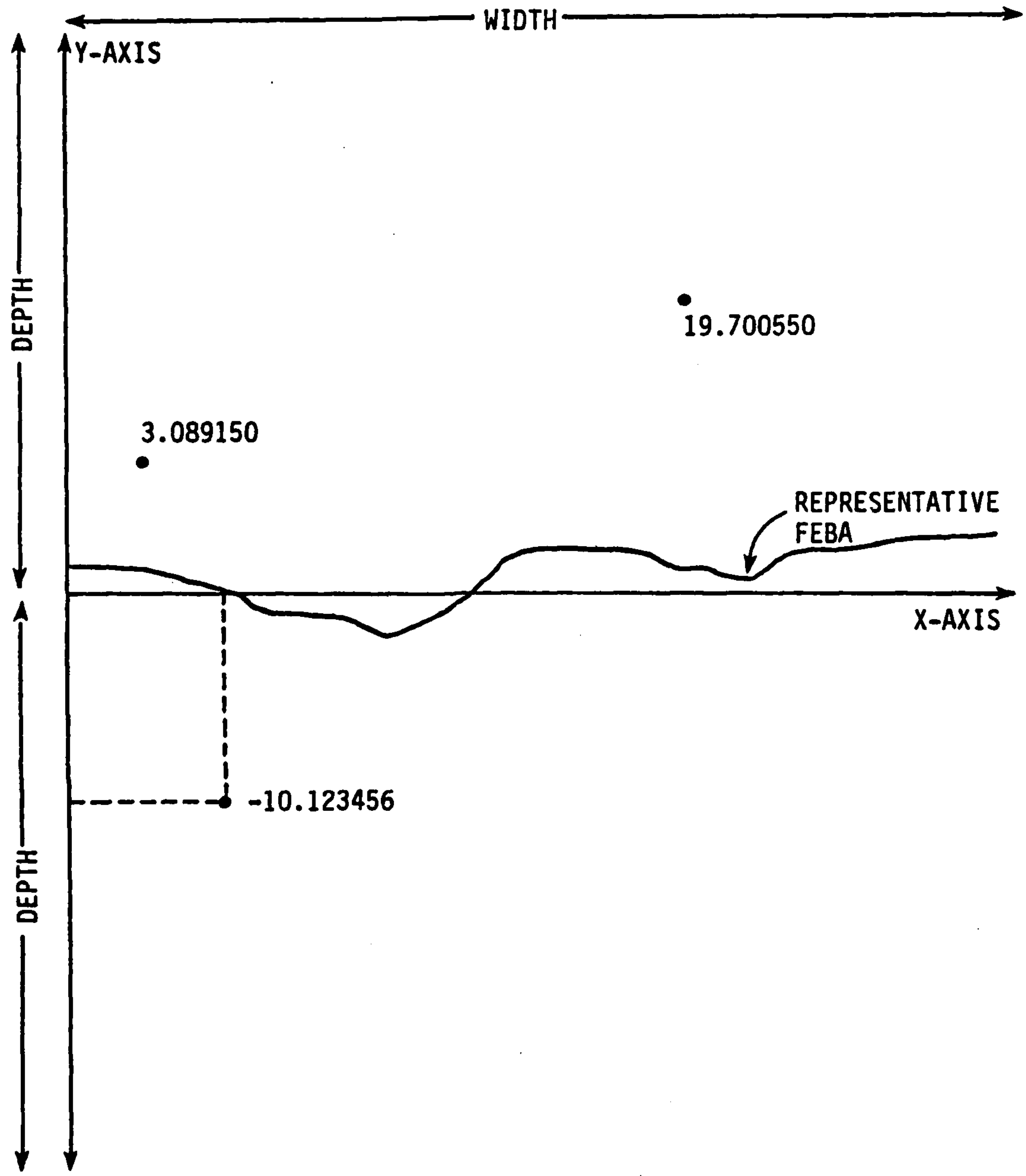


Figure 1. Example Scenario Area

Target Vulnerability Descriptions: Each target type must have a vulnerability characteristic specified for each class (nuclear, chemical and conventional) of weapon to be played in the allocation. In the case of nuclear vulnerability the target may be specified as having a Vulnerability Number (VN) as defined in reference 5. A brief description of the VN system is included here to provide continuity.

The VN system assumes that targets are classified as primarily subject to either overpressure damage effects ("P" type) or dynamic pressure damage effects ("Q" type), when assessing nuclear blast damage effects. Each VN specification has the form

$$VN = VN \begin{Bmatrix} P \\ Q \end{Bmatrix} K$$

where either a P or Q appears, but not both. The "VN" value is rounded to an integer representing a vulnerability class. Integral "P" values are separated by 20% in overpressure while integral "Q" values are separated by 44% in dynamic pressure. The "K" factor is rounded to a single digit. This K factor is a means of adjustment to the VN number and is used to adjust the VN to the yield of interest so that conventional cube root scaling relations may be employed.

The UNICORN methodology converts a coded value representing the VN value to a required pressure to produce damage by implementing the equations specified in reference 5 beginning on page I-25, and by curve fitted representations of figures I-4 and I-9 in reference 5.

The user may specify nuclear blast vulnerability by specifying a required pressure to produce target damage. In effect this short-cuts the VN conversion process.

Nuclear radiation vulnerability is expressed by defining a radiation level at which desired damage occurs. A target must be considered as either primarily vulnerable through damage to living tissue or through damage to electronic incapacitation. These levels are defined in terms of rads tissue or rads silicon. Since nuclear radiation may be modified as it passes through external walls, a transmission factor may also be defined. When defining this transmission factor, consideration should be paid to the desired target destruction effect. For example, if a radiation level of 5000 rads tissue is defined as sufficient to incapacitate a man, then the physical structure of the target must be considered.

Suppose the target is a medium tank company with X% of its personnel behind six inches of case-hardened steel. In this example, we assume that the transmission factor for such a steel shield is represented by a transmission factor of .8. That is, 80% of the external radiation level is actually effective on the interior. In such a case the required external radiation is actually a function of the kill criteria desired against a tank company, the rads tissue criteria, and the transmission factor. If the tanks themselves are considered to be the primary concern, then the target personnel outside of the tanks are neglected in defining target vulnerability. In such a case, a transmission factor of .8 would result in a UNICORN internal computation of radiation level required given by

$$\text{RAD req'd} = 5000/.8 \quad (1)$$

If, on the other hand, the personnel external to the tanks should be considered in assessing value destroyed then an average transmission factor must be computed which accounts for the unprotected men. Letting TF represent the actual transmission factor for the protected personnel, and X the percent of protected personnel then

$$\text{TF(modified)} = (100)(\text{TF})/(X + (100 - X)(\text{TF})) \quad (2)$$

This effectively lowers the required radiation level in the UNICORN target vulnerability assessment.

An entirely different vulnerability system must be utilized in specifying target vulnerability to chemical weapons. It is assumed that all possible battlefield chemical targets may be described by an equivalent circle. In addition, it is assumed that the target is under no special state of work and that it is completely available for exposure to chemical effects for some time as defined for each target by the analyst. It is also assumed that, in time periods of interest to UNICORN analysts, no target may be reduced in susceptibility to chemical agents through decontamination procedures. The UNICORN implementation has defined 21 target categories, which are listed in decreasing order of likelihood of target category in table 1. Each target is specified as having a masking time, a hood and gloves time and a posture. The posture category allows for variation by physical surroundings. Each category is intended as representative of a chemical warfare readiness condition. These category definitions were based upon consultations and data obtained from personnel responsible for estimating chemical weapons effectiveness for the Systems Analysis Directorate, Army Armament Command, and reference 6.

Table 1. Chemical Vulnerability Categories

Category	Masking Time	Hood and Gloves Time	Posture
1	15 seconds	45 seconds	None
2	15 seconds	45 seconds	Medium
3	15 seconds	45 seconds	Hard
4	15 seconds	45 seconds	Very hard
5	0 (mask on)	30 seconds	None
6	0 (mask on)	30 seconds	Medium
7	0 (mask on)	30 seconds	Hard
8	0 (mask on)	30 seconds	Very hard
9	0 (mask on)	0 (hood and gloves on)	None
10	0 (mask on)	0 (hood and gloves on)	Medium
11	0 (mask on)	0 (hood and gloves on)	Hard
12	0 (mask on)	0 (hood and gloves on)	Very hard
13	30 seconds	45 seconds	None
14	30 seconds	45 seconds	Medium
15	30 seconds	45 seconds	Hard
16	30 seconds	45 seconds	Very hard
17	No masks available	None available	None
18	No masks available	None available	Medium
19	No masks available	None available	Hard
20	No masks available	None available	Very hard
21 or above		CBR proof	

By definition, the target postures are:

None - Target unprotected in open.
Medium - Target in foxholes, bunkers or ventilated vehicles.
Hard - Target in covered trucks or armored vehicles with open hatches.
Very Hard - Target in closed armored vehicles.

A third target vulnerability system is utilized in defining target vulnerability to conventional weapon attack. In this case, a set of 39 categories are defined. Each target is assumed to consist of subelements, one of which is chosen as presenting the overall vulnerability characteristics. The user then chooses the category which has characteristics most nearly similar to the primary target subelements.

Target Location Uncertainty: Each target type may be considered to have an uncertainty associated with the location of the center of the target area. Such a value may represent errors in the location capability of target detection equipment. It may also represent location errors generated by unpredictable target repositioning between detection and attack. The model assumes that the target location uncertainty is a Gaussian distributed random variable. The mean is assumed zero, with circular error probable defined by user input. This value is permitted to be a function of distance in the positive y direction as measured from the scenario grid x-axis. The functional form is defined for the model by specifying a value of uncertainty at each of three distances. Figure 2 illustrates the technique. The user has specified three location uncertainty values (u) with three defined ranges (r) as the pairs (u_1, r_1), (u_2, r_2), (u_3, r_3). For any range lying between r_1 and r_3, a curve fit equation of the form

$$u = a + b(1 - Q^{(r - r_1)/(r_3 - r_1)}) \tag{3}$$

is used. For various values of a and b this particular functional form may be used to represent continuous functions which ascend or descend without reversing the sign of their slope. The curve fit assumes that for values of range greater than r_3 or less than r_1, all values of uncertainty are equal to the nearest specified values. Thus,

$$\begin{aligned} &u = a + b(1 - Q^{(r - r_1)/(r_3 - r_1)}) && r_1 < r < r_3 \\ &u = u_1 && r < r_1 \\ &u = u_3 && r > r_3, \text{ and} \\ &0 < r_1 < r_2 < r_3. \end{aligned} \tag{4}$$

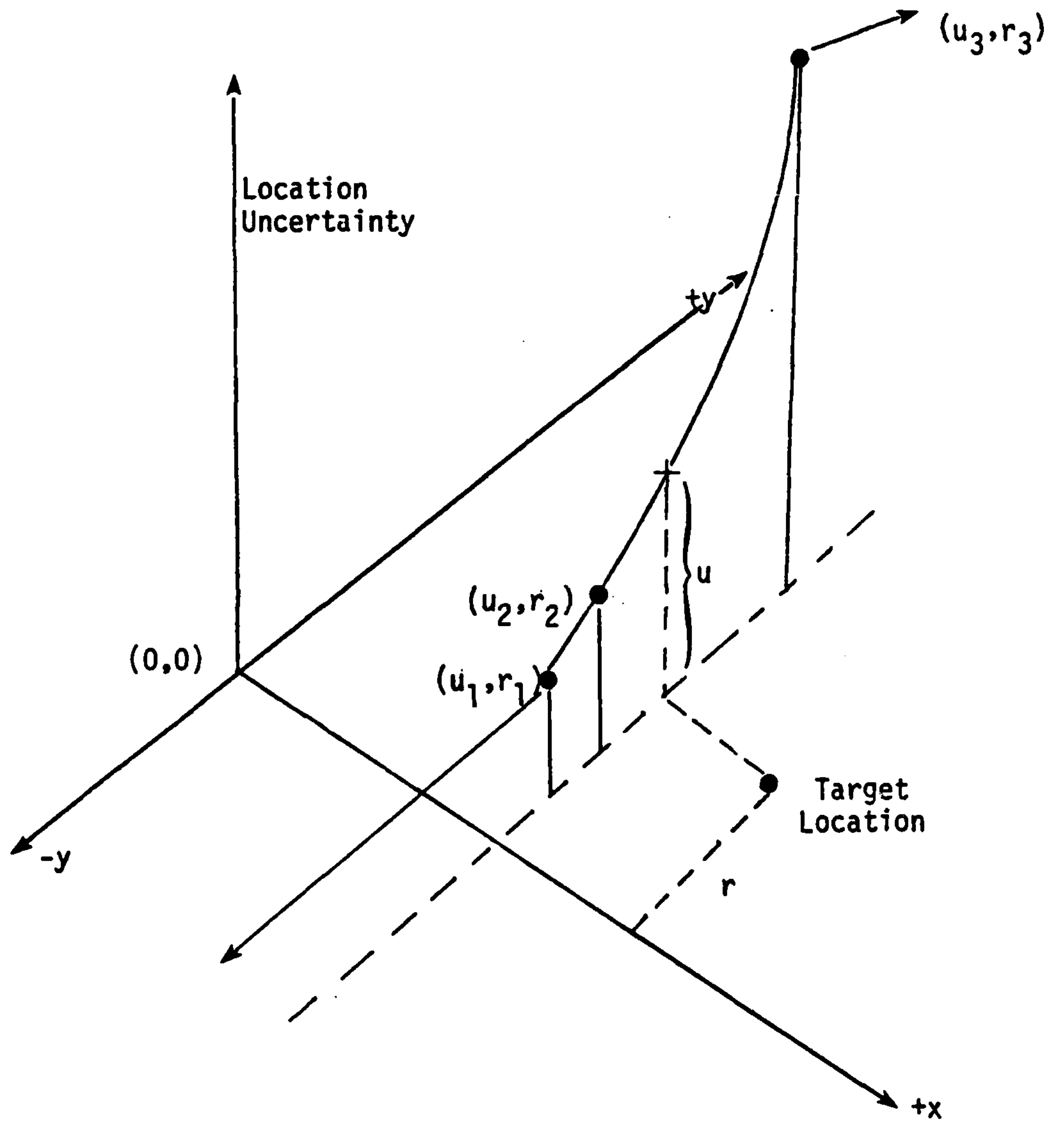


Figure 2. Illustration of Location Uncertainty Modeling

The location uncertainty for a particular target type at a location a distance from the x-axis is utilized in modifying the delivery accuracy of any attacking weapon. That is, the effect of uncertainty in target location is modeled as a nonreprogrammable error in impact point. The actual implementation assumes that the impact circular error probable (CEP) and the location uncertainty (U) are independent Gaussian random variables. A modified CEP is determined from

$$CEP = \sqrt{(CEP)^2 + (U)^2} \qquad (5)$$

thus including the location uncertainty by modifying the weapon impact distribution.

Weather/Darkness Considerations: In certain situations, UNICORN allows the user the capabiltiy to model man-in-the-loop corrections to target location uncertainty based upon weather/darkness conditions. A switch, IWDF, indicates to the program whether or not weather/darkness factors are to be considered. If off, the target location uncertainty is assumed zero for visually correcting aircraft delivery systems (JTYPE < 3) and the weather/darkness factor does not adjust the damage expectancy for the associated weapon type. If on, the target location uncertainty is modified by the complement of the input value of the weather darkness factor WDF; i.e.,

$$U = (1\text{-}WDF) * U$$

For JTYPE's > 2, the IWDF switch has no effect.

Weapon Effects Modeling: Each weapon class (nuclear, chemical and conventional) has a distinct methodology utilized in estimating weapon effectiveness. However, in each case, the process requires that a weapon radius be found. This is defined as WR such that

$$\int_0^{2\pi} \int_0^{WR} (1 - P(r))r\,dr\,d\theta = \int_0^{2\pi} \int_{WR}^{\infty} P(r)r\,dr\,d\theta \qquad (6)$$

where P(r) represents the probability of damage at range r, independent of direction. Equation (6) may be interpreted as specifying that the weapon radius is defined as that distance from DGZ such that the number of undamaged targets inside WR equals the number of damaged targets outside WR. Equation (6) may also be reduced to

$$WR^2 = 2 \int_0^{\infty} P(r)rdr. \tag{7}$$

This result relates the weapon radius to the expected damage radius E(r).

Nuclear Weapon's Effects: Two distinct nuclear effects modeling efforts have been included in UNICORN. One of these is based upon the Physical Vulnerability Handbook - Nuclear Weapons (reference 5). All early nuclear weapons effects modeled were based upon curve-fits to appropriate techniques defined in this manual. The second nuclear effects modeling effort has consisted of significantly more advanced effects modeling based upon the DNA Nuclear Effects Manual No. 1, EM-1 (reference 7). The UNICORN user may select computations based on either of these two models by appropriate specification of an input variable (IEMW). In either case, only blast or radiation is considered for determining weapon radii.

Nuclear blast effects modeling derived from the Physical Vulnerability Handbook assumes an optimal height of burst. The weapon radius of blast effect is computed based on a specified nuclear yield and a required pressure per square inch (PSI) to provide adequate target damage. The PSI value defines a probability of damage versus range function P(r) which, with equation (7), results in a weapon radius. The latter process actually uses a set of curve fit equations. The PSI value is determined from target type nuclear vulnerability input data.

Nuclear radiation effects modeling requires a nuclear yield and a required radiation level. The Physical Vulnerability Handbook derived approach does not distinguish between radiation to tissue and radiation to electronic devices. The same equations of effects are applied to either specification, however a warning message is printed if rads silicon is specified while utilizing this nuclear effects option. The process of determining the weapon radius is similar to the method used with blast (including the assumption of an optimal height of burst), however a required rads level is used to define a probability of damage function.

Nuclear effects modeling associated with EM-1 is performed through the use of a set of FORTRAN subroutines (collectively known as WEAR) (reference 8) developed at the La Jolla division of Science Applications, Incorporated.

These subroutines provide a more refined weapon radius value for both blast and radiation tissue attacks, and also compute a weapon radius for a rads silicon attack. The UNICORN implementation utilizes an optimum height of burst option in WEAR in determining the weapon radii for each type of attack.

The WEAR model also requires an additional weapon specification defining a weapon radiation characteristic class. (This is generally referred to as an "EM-1" type.) Unfortunately, the definition table is classified, although, given a class, the effect computation equations are not. Further clarification may be obtained from reference 7, page 5-25.

All nuclear effects computations are based upon a "conventional" weapons effects nuclear energy partition. The user may elect to approximate an other than conventional energy partition by specifying three different yield values for the same weapon: a blast yield, a radiation yield and a thermal yield. In this case, each type of yield will result in an estimate of weapon radius for the associated effect (thermal effects are not considered for weapon radii, but are considered in collateral effect computations). The weapon radius utilized depends on the type of attack specified. The largest weapon radius is utilized if UNICORN is permitted to choose the most effective attack. The same technique may also be utilized to model a weapon which has conventional energy partition, but which exhibits an enhanced or suppressed radiation characteristic.

Fracture Zones and Cratering: Cratering as a weapon lethality mechanism has been modeled in UNICORN. The radius of the fracture zone surrounding a surface or subsurface nuclear burst has been defined to be the radius of lethal effects for crater attacks. This fracture zone is estimated as a function of weapon yield, soil type, depth of burst and other factors. The effects of both earth penetrators and nonpenetrating nuclear weapons in cratering are modeled.

Cratering attacks by any nuclear weapon may be utilized against any target type, as specified by the user. The additional specification that a weapon under consideration is an earth penetrator provides the option of utilizing an optimal depth of burst, or any user-specified depth. The optimal depth of burst is defined as that depth at which the fracture zone is greatest, independent of other effects.

The user may also specify a cratering attack against an airfield runway. Since this target is not well modeled as a circle, the model invokes an effectiveness subroutine which models the particular characteristics of an airfield runway attack.

The weapon fracture radius is computed by a separate weapon lethality subroutine. The use of this subroutine has required the following assumptions:

(1) If an earth penetrator is to be used, optimal depth of burst or a specified depth is used. If the weapon is an ordinary nuclear weapon, a surface burst is assumed.

(2) .4 moles of neutrons/kiloton.

(3) If there is earth penetration, the hole is assumed partially filled. The fill factor is approximately that of a Pershing shallow-earth penetrator.

(4) Soil type is assumed to be dry soil and soft rock.

(5) Soil specific gravity is assumed to be 1.7 (similar to West German soil).

It has been assumed that earth penetrator weapons may be used for air burst attacks against any target not specifically requiring a crater attack.

The airfield attack methodology has required certain simplifying assumptions. The approach assumed:

(1) That attacks are upon airfield runways, and are carried out by surface or subsurface nuclear bursts. Attacks against aircraft, buildings or personnel must be modeled by defining a separate target type.

(2) The only damage phenomenon considered is the fracture zone surrounding a crater.

(3) Adequate damage is achieved by establishing a fracture zone across the entire width of the runway. A canonical runway has been assumed: width = 280 ft, length = 9,000 ft. (The model actually permits targeting of one "cut" for every specified runway. Multiple cuts must be modeled externally by specifying that extra targets exist.) The target area has been defined to be 280 ft in width by 500 ft in length.

A successful "cut" may be achieved in a variety of ways. Figure 3 illustrates the modeling approach.

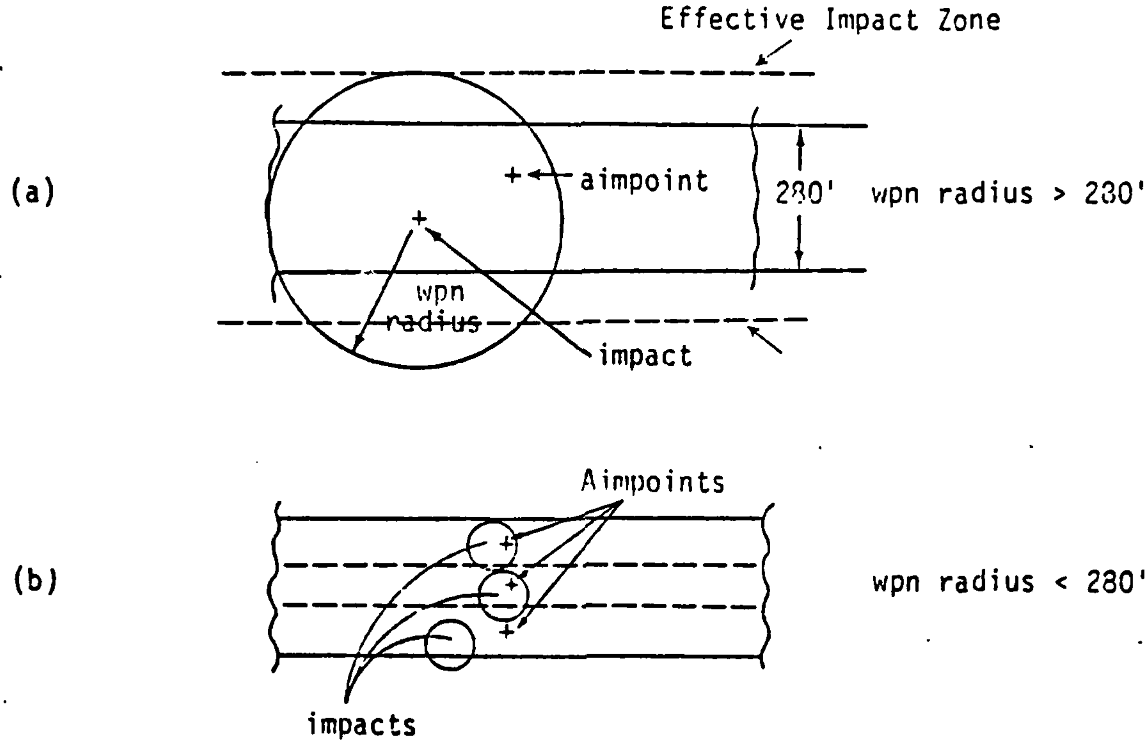


Figure 3. Runway Targeting

In the case of weapon fracture radius greater than the width of the runway, the zone within which effective impact occurs is greater than the defined target area. The individual probability of kill thus becomes the probability of impact within the enlarged area. In the case of weapon fracture radius less than the runway width, adequate target destruction requires that multiple aimpoints be utilized. These aimpoints are assumed to lie within rectangular areas of smaller width defined by the relationship of the weapon radius and the runway width. A success is defined by at least one impact within each subzone. The probability of kill is thus the combined probability of at least one impact within each subzone.

Chemical Weapon's Effects: The methodology approach implemented is based upon consultation with and data obtained from personnel currently responsible for estimating chemical weapons effectiveness for the Systems Analysis Directorate, Army Armament Command. Additional modeling has been based upon the weaponeering approaches defined in the Joint Munitions Effectiveness Manual, "Development of Open-End Hand-Calculation Methods for Estimating Chemical-Weapons Effectiveness" (reference 6).

The chemical weapons effects are computed by a module named CHEMPK. All chemical weapons effects computations result in a weapon radius which is then utilized in the same manner as in computations for any other weapon type.

Three chemical delivery system types are considered in CHEMPK and four different chemical agent loadings are allowed for them. These weapons may be used to fulfill one of three different missions against various targets as per the following definitions:

<u>Destruction</u> - The incapacitation of 100% of the target personnel within the time of interest.

<u>Degradation</u> - The subjection of the target unit to a chemical level (currently fixed at 5% casualties of unprotected troops) which forces its personnel to take protective action. This action in general degrades the quality of command and control within the target, reduces its mobility and causes heat stress among the target personnel.

<u>Contamination</u> - The deposition of liquid agent concentration upon a target to prevent its use to unprotected troops.

Certain key assumptions are made in CHEMPK during computation. These assumptions are outlined below, and should be understood and appreciated by analysts involved in study efforts using CHEMPK.

1. Weapon Radius - Chemical munitions' effectiveness is not well modeled by the lethal radius approach on a single munition basis. The reason for this is that chemical agents, unlike nuclear or HE/fragmentation weapons, are effective only over some specified time during which the agent may be influenced by meteorological conditions. The size and shape of a chemical effective coverage zone is highly dependent on these conditions and may be far from being describable by a circle. However, over an entire battlefield with numerous chemical fires being conducted with various munition types, the error of noncircular coverages may well average out, and it is based upon this assumption that lethal chemical areas are described via an equivalent lethal radius.

2. Meteorological Conditions - Due to the extreme dependence upon weather conditions of chemical agents' effectiveness as discussed above, certain assumtpions about the more dominating influences had to be made. In general, these consisted of assuming that calm weather exists over the entire area of chemical employments with the following conditions in effect:

   Atmospheric Stability - Neutral

   Temperature - 70^{o} F

   Windspeed - 5 Knots.

3. Terrain - It is assumed that all employments occur in open terrain.

4. Weapon Characteristics - It is assumed that all chemical weapon types with the exception of the spray tank may be described in accuracy through the parameter CEP. It is recognized that bursting projectile type munitions produce fragmentation. However, the accurate representation of such fragmentation effects was determined to be beyond the scope of this model. Thus the synergism of fragmentation upon chemical weapons effects is ignored in computing lethal radii. Finally, it is assumed that the lethal areas of chemical munitions may be optimally patterned as are the lethal areas of nuclear and conventional munitions during a run of UNICORN.

5. Friendly Forces - It is assumed that no friendly forces are affected by the employment of chemicals due to pre-warning and protective measures.

6. Fuzing - All bursting projectiles, bombs and bomblets are assumed to use PD (point-detonating) fuzing.

The computation of weapon radius invokes one of three methodologies depending upon the munition type. No way was found to use one methodology for all calculations due to the extreme differences in the characteristics of generic chemical delivery systems. The three methodologies are for bursting projectiles, spray tanks and massive bombs (or bomblets).

The methodology for calculating the effective coverage of bursting projectiles (bulk-filled) consists of curve-fitting detailed chemical effectiveness code outputs and sampling these curves. The key parameters in this process are the individual projectile fill weight, target hardness and agent type. Upon careful examination of chemical effectiveness code outputs, it was discovered that the effective coverage area of a given agent type in a bursting projectile against a target of a given personnel chemical protection category as a function of the projectile fill weight had a characteristic shape as shown in figure 4a, which if plotted on semi-log paper came out to be reasonably straight in all cases of interest (figure 4b).

It was also discovered that the effectiveness of chemicals against targets of a harder posture could be directly calculated by using a fill weight alteration factor which was agent dependent. For example, the effective area of a bursting projectile of 10 pounds agent fill weight might be some value when the projectile was used against a target in the open. If the same target were in a hard protective posture, however, such as being in an open APC, the effective area of the projectile might be reduced to a point at which a projectile fill weight of 3 pounds would give the same coverage to the target when in the open as a fully loaded projectile would produce against the target when in hard posture. The fill weight alteration factor in this case would then be .30. Finally, it was discovered that the effective areas of individual round coverage did not differ significantly as a function of volley size over a tactically significant time period. This means, for instance, that the effective area of a battery (six weapons) chemical volley was roughly six times that of a single round, that of a battalion volley (18 weapons) was roughly 18 times that of a single round and so on. Obviously, there are limits to how high this correlation may be carried without introducing unacceptable errors, but it seems safe to assume that battery and battalion volley levels and probably higher may be treated in this way.

The calculation of spray tank effectiveness involves several specific assumptions and is definitely target size dependent. The assumptions are:

> The spray delivery pass occurs directly upwind of the target on a line tangent to its edge.
>
> The aircraft delivering the spray flies a 450 knot straight-line path and delivers one complete tank per pass. This develops a swath of agent on the ground of approximately 2000 meters in length.
>
> The aircraft altitude is optimum for maximum effective swath width which is target protection category and size dependent. A constant windspeed of 5 knots is factored into this calculation.

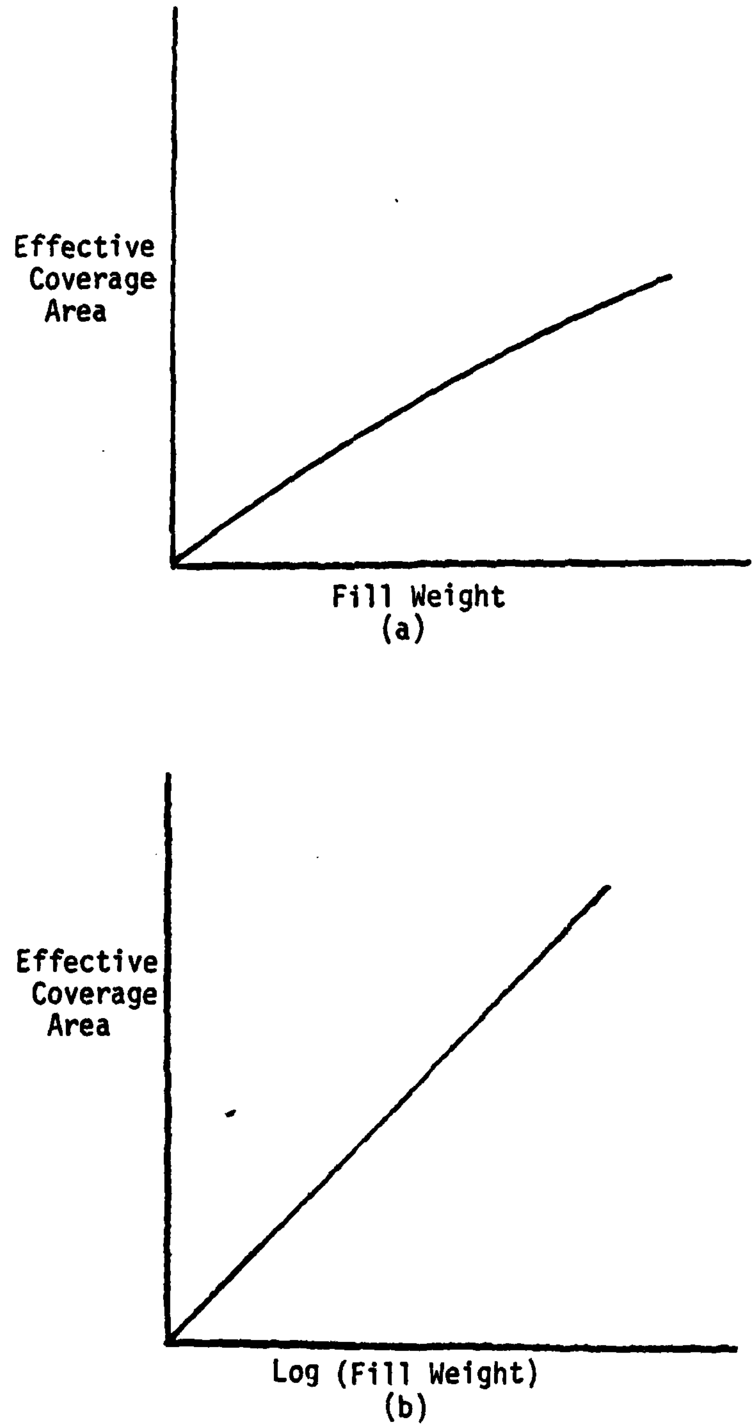


Figure 4. Representative Chemical Effectiveness Versus Fill Weight.

For a given target it is assumed that the effective swath is optimized as per target hardness and size under the assumptions outlined here and in the previous section. This swath will have an effective coverage of the target which may be converted into an equivalent effective radius. The "impact error" CEP figures used when considering the spray tank, involves only the target location uncertainty. It is assumed that the spray swath develops perfectly as just outlined and that the system "CEP" for it is therefore zero.

As in the case of the spray tank, many assumptions are made in each step of the evaluation of bomb or bomblet effective area. These steps as calculated in CHEMPK are in order:

1. The spacing, Δy, between bombs delivered in a stick is calculated using the formula

$$\Delta y = 5.4 * \sigma_{xy} \quad \left\{ \begin{array}{l} y \text{ is along flight path,} \\ x \text{ is transverse} \end{array} \right\} \tag{8}$$

   which assumes the bombs land in such a way that at least a mean incapacitating dose of agent is distributed all along the bombline. JMEM methodology (reference 6) defines this mean incapacitating dose contour as lying at 2.7 σ_{xy} (source cloud sigma in the ground plane) from the point of burst of a bomb or bomblet, thus landing 5.4 σ_{xy} apart will produce a source line of maximum length. This line is assumed to lie directly upwind of the target and tangent to its edge.

2. Because the spread of agent from a point of bomb or bomblet burst follows a distribution, adjustment must be made for unevenness of agent along the bombline. This adjustment factor is different for bombs and bomblets and is a function of bomb spacing as calculated in 1. CHEMPK stores tables of these adjustment figures, F_S, and extracts the proper one for Δy and munition type.

3. System and target location uncertainty CEPs are factored into the calculation of probability of mission fulfillment as the last step of CHEMPK operation. It is therefore assumed that, in calculation of bomb or bomblet effective area, the effective CEP is zero and that the expected fractional target length coverage ($\overline{L}/LT$) may be expressed as:

$$\overline{L}/LT = \underbrace{((\Delta y * \text{Number of bombs})}_{\text{Bombline or Source Line Length}}/D_T) * \underbrace{F_S}_{\text{Target Correction Factor for Spacing Diameter}} \tag{9}$$

4. The maximum effective downwind spread (W_E) of the source cloud is now calculated using the following relation, again drawn directly from JMEM methodology (reference 6):

$$W_E = (\text{Windspeed} * \text{Time of Interest} * 30.9) + 2.7\ \sigma_{xy} \quad (10)$$

In CHEMPK, the windspeed is currently fixed at 5 knots as previously mentioned and the time of interest is assumed to be the masking time of the target which CHEMPK calculated from input target chemical hardness or the maximum effective cloud growth time if no masks are available for it.

5. The expected fractional target width coverage, $\overline{E}av$, is now calculated again assuming for now that the bomb CEP may be ignored due to its use in probability of mission fulfillment computation later on.

$$\overline{E}av = W_E/D_T \quad (11)$$

6. The fraction of the target to respond to the agent, F_R, within the time period of interest is now computed. The expected coverage time, t_F, of the target is calculated using:

$$t_F = (\overline{E}av * D_T)/(\text{Windspeed} * 30.9) \quad (12)$$

and assuming in this case that the time of interest is the GB response time of 6 minutes, F_R is set according to the following table:

$$\begin{aligned} F_R &= .62 \text{ for } t_F \geq 4 \text{ minutes} \\ &= .78 \text{ for } t_F = 3 - 4 \text{ minutes} \quad (13) \\ &= .86 \text{ for } t_F = 2 - 3 \text{ minutes} \\ &= .94 \text{ for } t_F = 0 - 2 \text{ minutes.} \end{aligned}$$

7. Finally, the expected fractional casualties inflicted on the target, F_K, by the stick of bombs or dispenser load of bomblets is calculated:

$$F_K = \overline{L}/LT * Eav * F_R * F_S. \quad (14)$$

This expected casualty level may be equated to an expected target area coverage from which an effective radius is drawn. This radius, as in the previous two methodologies, is now utilized by CHEMPK for the calculation of probability of mission fulfillment parameters which are returned to the calling routine.

Conventional Weapons Effects: The methodology approach implemented is based upon data obtained from personnel at the Systems Analysis Directorate, Army Armament Command, however the bulk of the methodology is based on various volumes of the Joint Munitions Effectiveness Manuals (reference 9). The computations are performed by a module named COMPLR. These weapons may be used to fulfill either a complete target destruction mission or a tactical neutralization mission. The definition for these missions varies by target type but for example, a "K" kill for vehicles or an "F" kill for artillery would be considered a target destruction mission. Tactical neutralization should be identified with immediate incapacitation but permitting possible repair.

Certain key assumptions are made in COMPLR during computation.

1. Weapon Radius - Many munitions have noncircular patterns of effects; flame weapons for example have a very elliptical area of coverage, and fragmentation patterns are very complex. It has been assumed that on the average over a wide range of employment that each weapon type's noncircular patterns average out in such a manner as to be described by circular weapons effects.

2. Terminal Delivery - As appropriate for delivery systems with target discrimination capability, the model assumes that target subelements are aimpoints rather than in some optimal pattern over the target area. This is applied in the case of all air-to-surface conventional weapons, except CBU's under pilot control. In cases without terminal subelement discrimination, optimal patterning of weapons is assumed.

The key to the computation of conventional weapons effectiveness is in the computation of a lethal radius for any munition against any target. If a weapon/target combination was not considered in the JMEM (reference 9), then the weapon radius is assumed zero. For feasible combinations, a WR is returned as a function of warhead weight, delivery type and warhead type. One of four curve-fit formulas is used (figure 5). The parameters of these curve-fit equations are stored in COMPLR and were derived by least squares-fitting procedures.

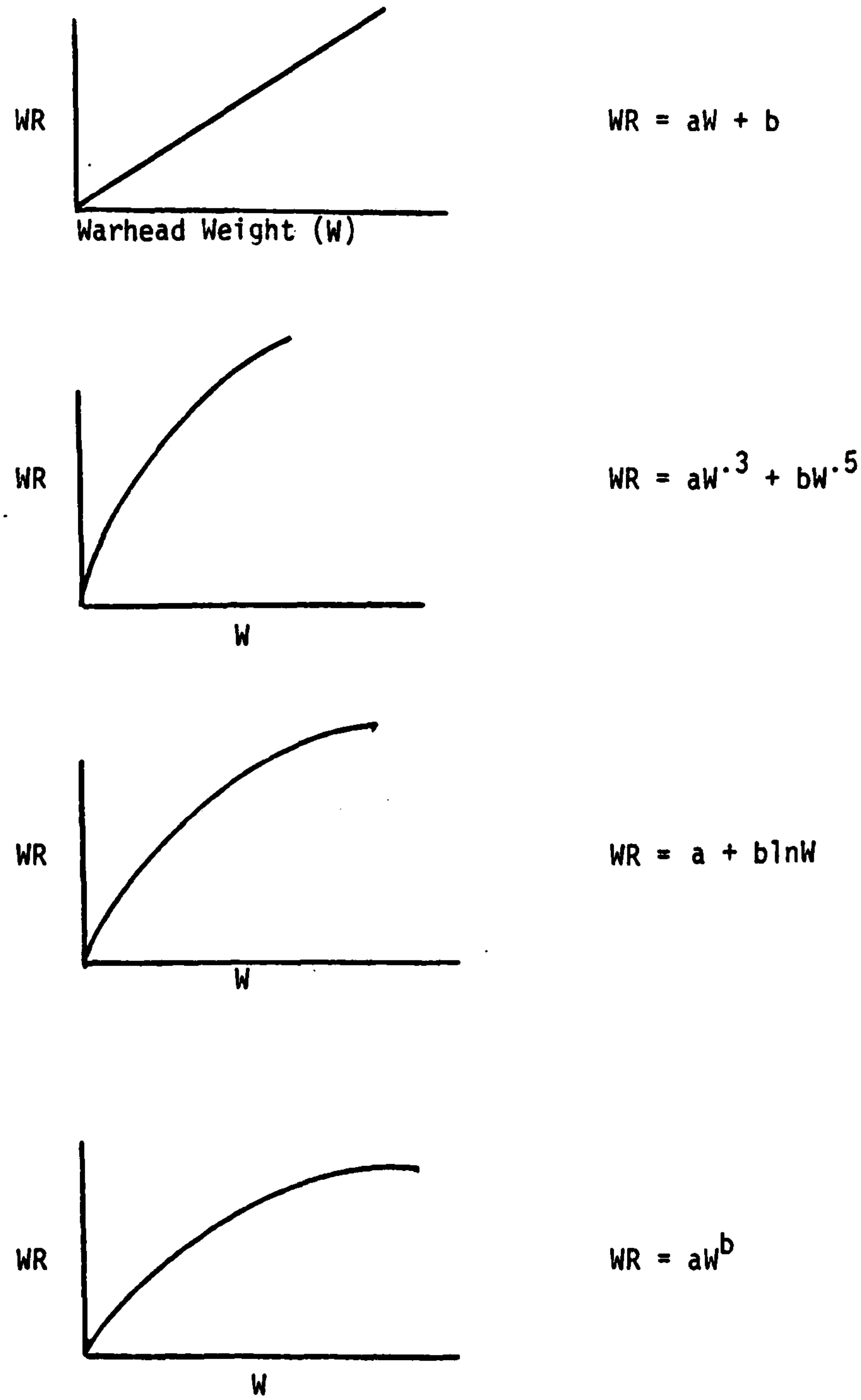


Figure 5. Conventional Weapon Radius Curve Fit Forms

Weapon Accuracy: Each weapon type may have a range-dependent accuracy characteristic. Each weapon is assumed to have a Gaussian impact distribution with zero mean and a range-dependent Circular Error Probable (CEP). The user is permitted to specify the CEP at three values of range (r) from launch point (figure 6). For any weapon launch point/target location combination an actual range is computed. Then a curve fit based on the three data pairs is used in estimating the CEP at the actual range. The relationship is similar to equation (4) in that CEP is assumed to be either monotonically increasing or decreasing with range. The relationship is given by

$$CEP = a + b(1 - Q^{(r - r_1)/(r_3 - r_1)}) \qquad r_1 \leq r \leq r_3$$

$$CEP = CEP_1 \qquad r < r_1 \qquad (15)$$

$$CEP = CEP_3 \qquad r > r_3, \text{ and}$$

$$r_1 < r_2 < r_3.$$

This CEP value may be modified (as discussed previously) by the target location uncertainty.

Damage Functions: The UNICORN allocation process requires that a functional relationship be specified which relates target destruction to number of weapons employed for every weapon launch point/target location combination. This relationship is termed a damage function. These functions include the effects of weapon lethality, delivery accuracy, non-reprogrammable weapon reliabilities, and target hardness. The general form for all UNICORN damage functions is

$$VD(n) = V(1 - (1 - P)^{n - T}) \qquad n \geq x \qquad (16)$$

$$VD(n) = V(n/x)(1 - (1 - P)^{x - T}) \qquad n < x$$

where V represents target value, P, T and x are curve-fit parameters, and n is the integer number of weapons. This equation represents a curve fit to the value destroyed by the attacker for n weapons of a particular type in an attack on a particular target. Figure 7 illustrates this functional form.

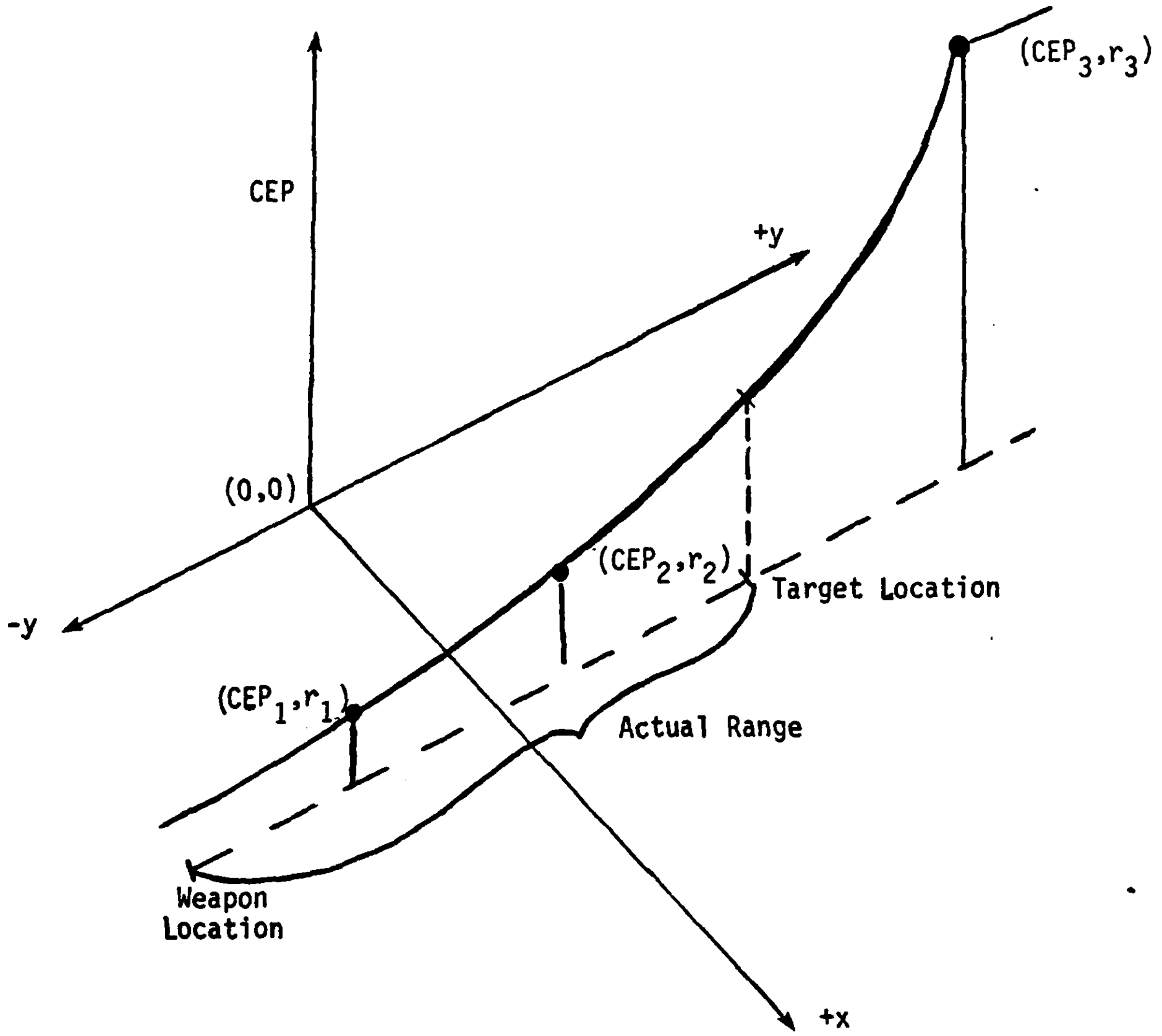


Figure 6. Weapon Accuracy Modeling

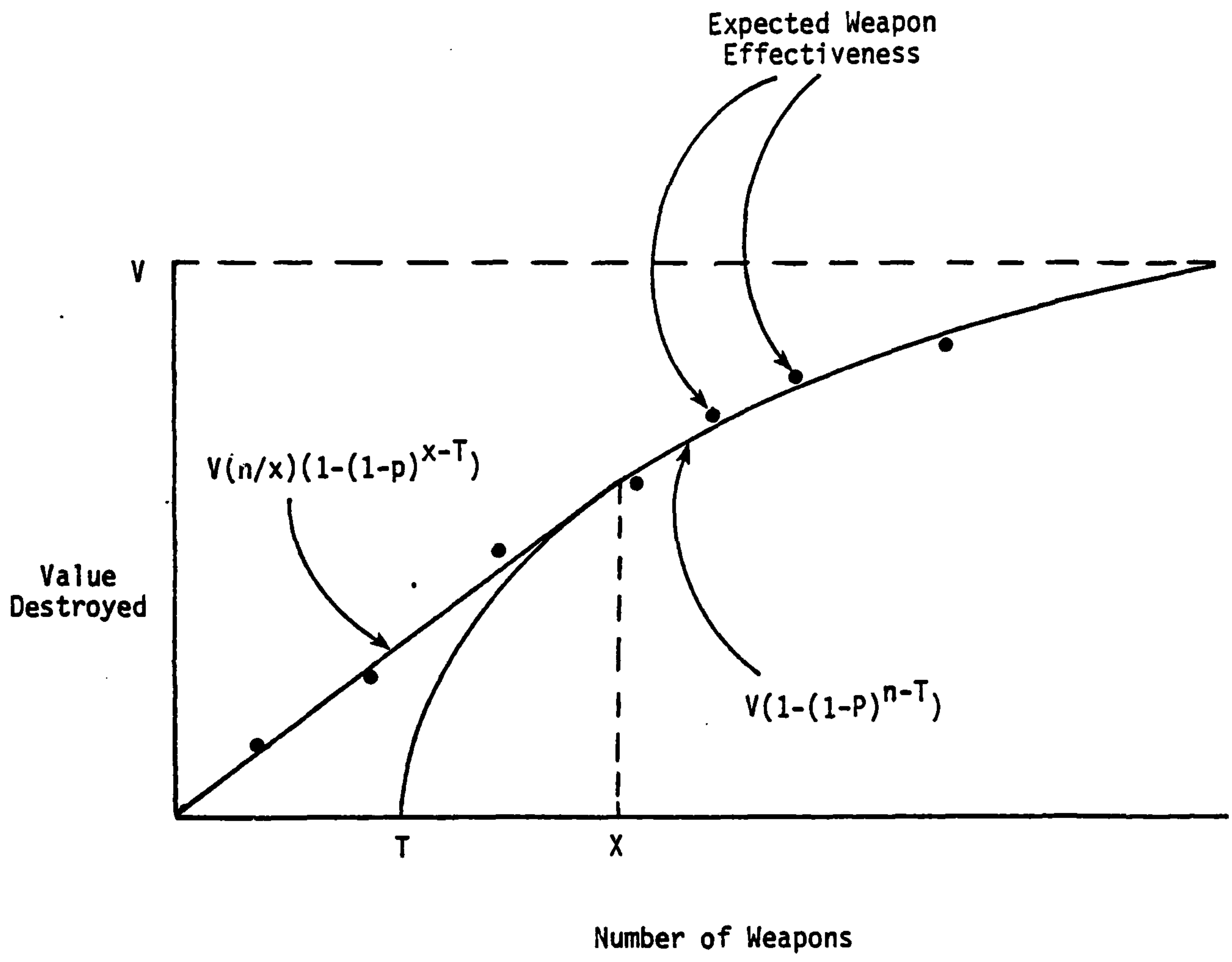


Figure 7. Illustrative Damage Function

The model damage function is a curve fit to the expected weapon effectiveness values. Generally, if a target is viewed as a circle of finite area, and weapons effects are modeled as "cookie cutters", with full effectiveness within the weapon radius and zero without, then there may be a linear return per weapon for the first few weapons. Figure 7 shows this effect and the portion of the curve fit which corresponds to it. As more weapons are applied to the target a point will be reached at which the weapon effects cookie cutters begin to overlap, thus yielding a decreasing value destroyed per additional weapon. The curve fit to this portion of the damage effectiveness values is used only for values of $n \geq x$, where x represents a point at which tangency to a straight line from the origin occurs.

The calculation of a damage function in UNICORN requires that the user define a criterion for sufficient damage against each target type. This damage criterion defines a point in the attack at which no additional weapons should be expended to achieve more destruction on a target of that type. The selected criterion should reflect the effect derived from the attack. Changing the criterion will change the curve-fitted damage function and thus the relative effectiveness of the individual weapons. One criterion of interest uses expected value calculations (roughly analogous to 50% confidence level) and permits essentially total destruction of a given target. This is referred to as "expected damage" criterion. A second damage criterion which has been widely utilized in nuclear weapon targeting specifies a minimum probability of achieving a fractional target coverage. A popular example of this latter criterion is the 90/30 criterion. That is

$$\text{Prob}(\text{Coverage} \geq .3) \geq .9 \qquad (17)$$

In effect, this example requires that a strategy be utilized which provides 30% target coverage (at a specified lethality level) with 90% confidence. In this case, full target value is credited if a strategy is carried out which satisfies this criterion.

In the case of one-weapon attacks this criterion may be interpreted as illustrated in figure 8. The approach assumes that a single weapon is aimed at the center of the target and has an impact distribution defined by a circular Gaussian distribution. It is then easy to define a circle which is concentric with the target and which defines the outer limit for 90% of such impacts:

$$R = (\text{CEP}) \left(\sqrt{-2(\ln(1-.9))}\right)/1.1774 \qquad (18)$$

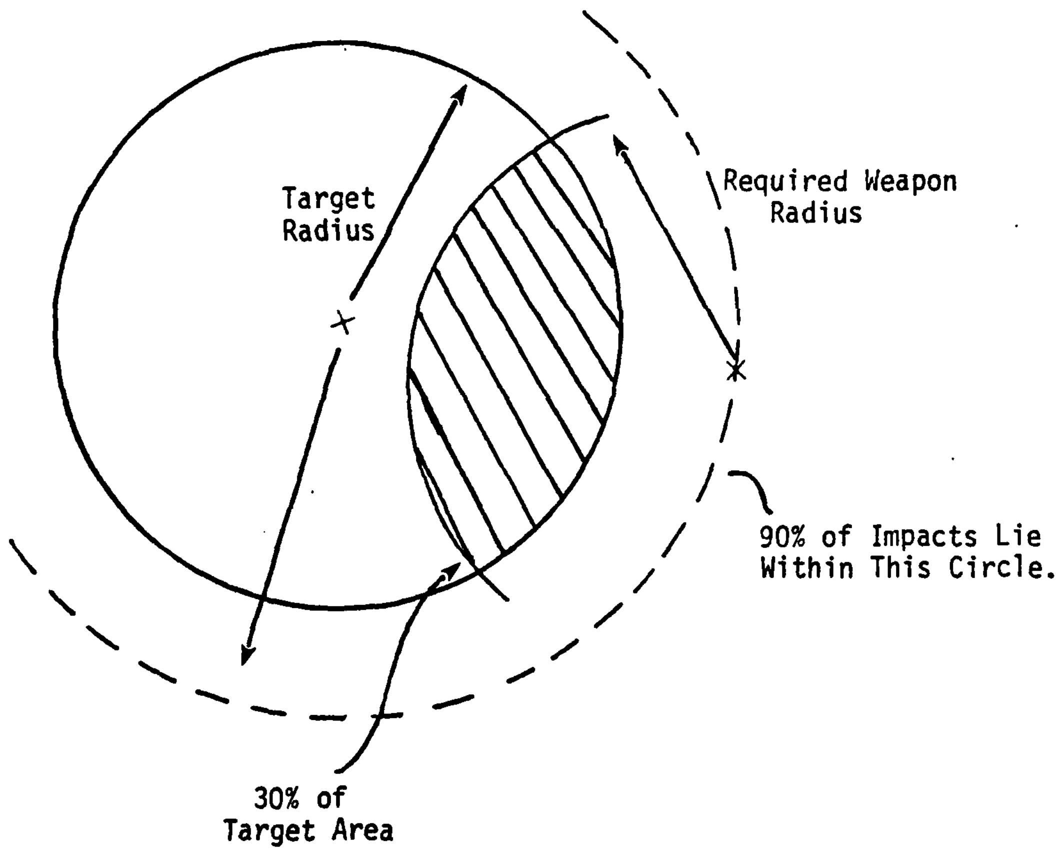


Figure 8. Damage Criteria: 90% Confidence, 30% Coverage

An impact on a circle of radius R will satisfy the damage criterion if its weapon radius is large enough so that the intersection of the target circle and the weapon radius circle is at least 30%. That is, 90% of the impacts would result in at least 30% target coverage.

In the case in which a single weapon will not provide the required confidence/coverage, then a closed form solution similar to equation (18) is not known.

A heuristic procedure has been adopted in UNICORN which provides mathematically correct results for "expected damage" criterion computations and for the confidence/coverage criterion (the user is free to select any set of values) if a single weapon will achieve the specified level. The procedure is approximately correct for cases in which multiple weapons are required. As implemented in UNICORN, the procedure requires that a confidence and coverage be defined for every target type.

The procedure defines an equivalent target radius based on the weapon CEP, original target radius and the confidence and coverage damage criterion for the target type. The method defines the equivalent of target radius to be equal to the minimum required weapon radius, for a single weapon attack, as illustrated in figure 8. Since the required weapon radius computation has included the effects of weapon impact errors, the actual weapons are assumed perfectly accurate. In an actual case in which the CEP is approximately zero, this approach will result in an equivalent target radius very nearly such that its enclosed area would be equal to the required confidence times the target area. That is

$$\text{Equivalent Area} = (\text{CON})\ \pi\ (\text{TR})^2 \tag{19}$$

By targeting the equivalent area in an optimal manner, a damage function results which approximates the true optimal damage function. Similarly, in any case in which the equivalent target area would fall mostly within the actual target, the damage function will be approximately correct. The resulting damage function is also approximately correct whenever the equivalent target radius is on the order of the actual weapon radius.

An expected damage attack is performed whenever the required coverage is greater than or equal to 99.9% and the confidence is less than .1%. This removes any effect of weapon CEP on the equivalent target radius. The resulting equivalent target radius is very nearly the actual target radius, and the result is the equivalent of actually targeting the entire target area. The actual CEP is used in this case in determining the damage function.

Linear Targets: The UNICORN methodology provides the user the capability of specifying certain target types to be linear in nature as, for example, a tank battalion or truck convoy moving along a road. In such instances a negative target radius indicates the length in meters of the line target and the target location point indicates the geograhical center of the line target. No orientation with respect to the FEBA or other targets is specified as this is not needed for current calculation purposes. Note that linear targets are not considered for conventional or chemical attack nor are they treated in the military collateral damage assessment model.

As with other targets, damage assessed against linear targets is given by a damage function curve of the form shown in equation (16). The P, T and x values are determined by a least squares fit to data points derived from a special purpose routine designed to return probability of kill as a function of the number of weapons employed, weapon radius, weapon CEP, weapon reliability, target length, and target location uncertainty. Target value is assumed to be uniformally distributed along the length of the linear target.

Given that n weapons are attacking a line target, the line is divided into n segments of equal length. The centers of these segments are allocated as weapon aimpoints. Each segment in turn is also divided into m segments. m is always an odd integer. The target value represented by each of these m segments is assumed to be accumulated at the center point of each segment.

The probability that value point i is not damaged by a weapon aimed at aimpoint k (q_{ik}) is the probability that a weapon aimed at k hits outside a circle of radius R_L, where R_L is the lethal radius of the weapon, circumscribed about point i. Here R_L is the single value represented by the "cookie cutter" damage function. Further we assume impacts are distributed about k with a circular normal distribution defined by weapon CEP and target location uncertainty.

An approximation procedure to compute

$$P_{ik} = 1 - q_{ik}$$

is given in reference 10. Thus if n weapons are allocated to the line, the probability that value point i survives is given by

$$P_{s_i} = \prod_{k=1}^{n} (1 - P_{ik}) = \prod_{k=1}^{n} q_{ik}$$

Thus the probability that i is covered by at least one of the weapons effects circles is

$$P_{kill_i} = 1 - P_{s_i} = 1 - \prod_{k=1}^{n} (1 - P_{ik})$$

Given that there are a total of m value points covering the entire line, the expected value returned given n weapons were used is

$$E\ \{kill|n\ weapons\} = \frac{\sum_{i=1}^{m} (1 - \prod_{k=1}^{n} (1 - P_{ik}))}{m}$$

These expected kill values are then used as input to the least square curve fit routine to compute the P, T and x parameters.

This procedure yields only an approximation to actual damage derived. It is sensitive to both aimpoint location and the number of value points associated with each aimpoint segment. Procedures used within UNICORN use empirically derived heuristics to minimize sensitivities due to both of the above metnioned areas.

One additional point of concern is run time. For small weapon radius/large CEP combinations the number of weapons needed to generate kill levels for the entire target length of > .99 can be very large. To minimize run time in these special instances an alternate procedure is invoked. The probability of kill with one weapon, PK(1), is calculated using the above procedure. This value is then used to estimate the values for T and x as follows:

$$T = \hat{n} - \ln(1. - PK(\hat{n})) / Q$$
$$x = T + \ln(- PK(1) / Q) / Q \qquad (20)$$

where

$$\hat{n} = 1./PK(1) + 1.$$
$$Q = \ln(1. - P) \qquad (21)$$
$$P = 2. - \frac{PK(\hat{n}+2) - PK(\hat{n})}{PK(\hat{n}+1) - PK(\hat{n})}$$

This procedure shows significant decreases in run time compared to the general procedure and has little effect on the accuracy of the damage function representation.

Air Deliverable Weapons: UNICORN provides a variety of user-specified controls which govern the user of air deliverable weapons within UNICORN. Options include: air defense modeling with area interceptors, area SAM sites and terminal defense sites; an air loading model which allows assignment of aircraft to specified weapon types according to a heirarchy level specified by the user; the capability of specifying certain weapon locations at which a desired fraction of the force is assigned armed reconnaissance status; the capability of specifying certain weapon types from which a specified fraction of the force can be assigned loiter point status; and a switch which determines the effect of weather/darkness on location uncertainty.

Each of the above options can be independently or concurrently invoked within UNICORN via user inputs. The default option is not to invoke any of the above options. The default option does not preclude use of air deliverable weapons, but it greatly increases the detail involved in preparation of inputs.

Air Defense: The UNICORN model permits the user to include the effects of area aircraft interceptor defenses, area SAM defenses and SAM terminal defenses near specific target locations. Only aircraft-delivered weapons are affected by these defenses. In each case, the implementation procedure actually modifies the associated weapon launch point/target location combination damage function. The analyst may exercise any of the defense options on either of two levels of detail. The first level requires aggregate penetration probabilities or area SAM defense suppression prices as input. This level is intended for use when overall results of offense-defense encounters can be more easily estimated than results of one-on-one duels. The more detailed level can be invoked when knowledge of single interceptor attacker contests is available. This second level tunes results to the actual level of attack and defense as opposed to the averaged results of the more simply defined penetration probabilities or defense suppression prices. These latter approaches may also be used to model air superiority effects.

The area defense consists of intercepting aircraft which must be penetrated by all offensive aircraft. Defenders are assigned uniformly to the attackers with the final result of the encounter being a penetration probability. This probability is used to modify the inflight reliability of air-delivered weapons.

The suppression of a specified fraction of area defensive SAM sites may be required. The actual sites and weapons used are determined in the optimization process. Although the model treats the sites as targets of no value, their suppression is required by a constraint on the solution of the linear programming problem. Once the requisite number of sites have been suppressed, these SAM sites have no further effect.

SAM sites assigned to the defense of single target locations comprise the terminal defense. This defense is the most highly refined one available in UNICORN. The SAM sites can present either a perfect or a leaky defense (an occasional attacker succeeds) to the incoming aircraft. Probable damage levels corresponding to various levels of attack are calculated and a general damage function generated to fit this data.

The air defense model in UNICORN has been designed to be consistent with the level of detail in the remainder of the model, and to provide support for the main functions of the UNICORN model. As such, certain simplifying assumptions have been made in the air defense model.

- Defense against air-delivered weapons only
- No penetration aids
- Island defenses not modeled
- Depenetration kills (aircraft intercepted after bomb release) not explicitly treated
- Defense suppression sites not associated with specific target attacks.

Within these limitations, however, the model is flexible enough to approximate the overall effects of defense in general tactics and strategies. The analyst may vary input parameters to isolate those which most significantly influence final outcomes, and consequently must be most carefully determined.

A general area defense not unlike a combat air patrol is the first defensive option. The possibility for encounter modifies the inflight reliability of the aircraft and occurs before any target is attacked. A probability of penetrating this defense may be input for each weapon type. Alternately the model can calculate the probability using a minimal amount of input via the following equation:

$$P_{PEN} = 1 - P_E + P_E\,(1 - P_{SPK})^{NIP/NB} \qquad (22)$$

where

P_E = probability of encountering a defensive interceptor.

P_{SPK} = probability that an interceptor pass kills the attacker.

NIP = total number of interceptor passes made by the defense.

NB = total number of aircraft encountering the defense.

Calculation or estimation of either P_E or P_{SPK} is difficult at best. To simplify the analyst's task, P_E is assumed to be one, and only P_{SPK} need be input. Effects of defense destruction, though not explicitly treated, can be reflected by a smaller NIP. The number of passes must be known a priori, however, since the value is input at the beginning of the problem and not modified within the program. Because of the complexity involved in changing the number of bombers allocated with each shift in strategies, NB is set equal to the total number of bombers that could possibly be allocated. If a smaller number is actually used, an underestimation of defensive effects would result. If this problem is anticipated, NIP may be increased accordingly to effect a proper ratio of interceptor passes to bombers.

If P_{SPK} is input as zero for an air-delivered weapon type, it is assumed the user intends the aircraft to skirt the defenses. In this case the total number of bombers used in eq. (22) does not include these aircraft. Total aircraft is calculated by

$$NB = \sum_I BL(I) \cdot BATL(I) \tag{23}$$

where

BL = number of planes per squadron (equivalent to launches per battery for surface-fired weapons)

BATL = number of squadron or tactical air groups at a "location" (equivalent to number of batteries at a launch point).

The index, I, varies over all weapon launch points used by air-delivered weapons.

A second defensive option in UNICORN is the requirement for the suppression of a number of SAM sites arbitrarily placed in the target grid by the user. The sites are regarded as targets, a specified fraction of which must be suppressed. A zero target value is usually assigned to the suppression sites since the requirement for attacking them is a constraint on the allocation. If a positive payoff is to be assigned to the sites, it should be noted (as will be explained shortly) that suppression is not equivalent to destruction. Weapons allocated against the SAM sites are drawn from the available arsenal and are, of course, no longer available for destruction of other targets.

A maximum of three sets of area SAM characteristics of SAM site "types" are allowed. The SAM suppression mission is modeled as a subtractive type defense. A defense suppression price, DSP, in number of weapons, is assigned for a particular weapon type. This price may be either input by the user or calculated within the model. When calculated,

$$DSP = MINIMUM \{N_x, N_k\} \tag{24}$$

where

N_x is the number of weapons needed to exhaust the site of its usable SAMs, and

N_k is the number of weapons required to insure high confidence of site destruction.

$$N_x = NMPS/(NMPA * PACQ * RLW * PWO) \tag{25}$$

where

NMPS = number of missiles (SAMs) available at the site

NMPA = number of missiles allocated against an attacker

PACQ = probability of acquisition of the attacker by the site

RLW = reliability of the attacking weapon

PWO = number of detected objects per warhead (includes decoys).

The simplifying assumptions that PACQ = PWO = 1 are made, resulting in $N_x = NMPS/(NMPA * RLW)$.

N_k is defined by the following equation:

$$N_k = \ln (1 - CON)/\ln (1 - P^1) + T^1 + 1 \tag{26}$$

where

CON = desired confidence of site destruction

P^1, T^1 = parameters from the general damage function.

P^1 and T^1 are those values resulting from an undefended target attack modified by the defensive capabilities of the SAM site as follows:

First the probability, PPEN, of penetrating the SAM site's defensive capability is computed

$$PPEN = 1 - PACQ + PACQ\ (1 - PSIK)^{NMPA} \tag{27}$$

where

PACQ, NMPA = same as in eq. (24), and

PSIK = probability of a single interceptor killing the attacker.

Then

$$P^1 = P \cdot PPEN$$

where P is the undefended target damage function parameter and

$$T^1 = \begin{cases} \dfrac{1}{A^1} + \dfrac{1 - \ln(A^1/(-\ln(1-P^1)))}{\ln(1 - P^1)} & \text{if } A^1 < -\ln(1 - P^1) \\ \\ 0 & \text{otherwise.} \end{cases} \quad (28)$$

Here A^1 is slope of the line tangent to the damage function and passing through the origin.

This line represents the maximum damage per weapon achievable against the site.

A^1 is approximated from A, the slope of the line tangent to the undefended damage function, by $A^1 = A \cdot PPEN$.

Any weapon may be used to suppress the site, but only air-delivered weapons can be effected by the SAMs.

The final defensive option available in UNICORN is a terminal defense at each target location. Once again only air-delivered weapons are effected by the terminal defense. A penetration probability, used as a reliability modifier in the same manner as the area defense model, may be input for each location. The more refined terminal defense consists of an input number of SAM sites at each location. Three distinct SAM types are allowed within the model, but only one type per location. This defense is an imperfect defense which allows penetrators to leak through and cause damage. Two routines adapted from the Arsenal Exchange Model (AEM) calculate the leakage and compute a revised damage function based on this leakage. Chapter IV-B of reference 11 should be consulted for a complete explanation of the methodology. A brief summary follows.

Three tactical situations are possible:

OPTION 1: A sequential attack is used in which the first penetrating warhead eliminates the defense. The defense does not know the extent of the attack and assigns a constant number of missiles to each attacker until the defense is exhausted or destroyed.

OPTION 2: The attack is the same as in option 1, but the defense assigns missiles in accordance with the Prim-Read doctrine (see Appendix C of reference 11).

OPTION 3: The attack is in the form of a simultaneous salvo of warheads. The defense knows the extent of the attack and cannot be killed. SAMs are then allocated uniformly (insofar as is possible in integers) to counter the attack.

For each combination of weapon and target location, the damage probability for various attack levels is computed. Allowance is made for the type of SAM, the defense doctrine and the defense performance as specified by input variables. Damage level as a function of number of weapons used is then fit by the standard damage function, $PK = 1 - (1 - P)^{N} - T$. Final results of the terminal defense take the form of modified P and T values.

Air Loading: The UNICORN model permits the user the option of invoking an air loading model. The procedure assigns aircraft to various weapon types based upon weapon type priorities, the number of aircraft available of each type, the number of rounds available at each location to which aircraft can be assigned and the number of weapons of various types that each aircraft can carry. These values are then used to compute the number of aircraft assigned to each location where air deliverable weapon types are used. This assignment is a sequential procedure with those weapon types with highest priority receiving their required aircraft first, next highest priority next and etc. Implicit in the assignment algorithm is an aircraft priority based upon the order aircraft information is input. Thus aircraft type number 1 whenever possible will be assigned before aircraft type number 2, and etc.

Mathematically, the procedure for assigning aircraft is as follows:

The set $P_N = \{i | i$ is a valid weapon type number and $IACRPR_i = N\}$, where $IACRPR_i$ is the priority of weapon type i, and N a positive integer, and the set $L_i = \{\ell | \ell$ is a valid weapon location with weapon type i$\}$ for each $i \in P_N$ are defined, along with the following variables:

$Total_i$ = total number of rounds of weapon type i that are available for air loading.

$ACROH_\ell$ = total number of rounds available at location ℓ.

$ACN_{NA,N}$ = total number of aircraft of type NA assigned to priority set P_N.

$ACI_{NA,i}$ = total number of aircraft of type NA assigned to weapon type i.

$ACNUM_{NA}$ = total number of aircraft of type NA still available to be assigned.

$ACL_{NA,\ell}$ = total number of aircraft of type NA assigned to location ℓ.

$F_{NA,i}$ = the fraction of aircraft of type NA that compose all of the aircraft assigned to weapon type i.

RF_{NA} = sortie rate/hour of an aircraft of type NA.

DF_i = time over which weapons of type i can be delivered by aircraft.

$ACLOAD_{NA,i}$ = the number of rounds of weapon type i an aircraft of type NA can carry.

Then for n = 1,2,3..., and each non empty set P_N,

$$Total_i = \sum_{\ell \in L_i} ACROH_\ell \text{ for each non empty set } L_i,\ i \in P_R \tag{29}$$

$$ACI_{NA,i} = Total_i/(RF_{NA} * DF_i * ACLOAD_{NA,i}) \text{ for each aircraft type NA.} \tag{30}$$

Thus

$$ACN_{NA,N} = \sum_{i \in P_N} ACI_{NA,I} \ . \tag{31}$$

If $ACNUM_{NA} \geq ACN_{NA,N}$, aircraft NA is assigned to carry all available weapons of type i such that $i \in P_N$ and $ACL_{NA,i}$ and $F_{NA,i}$ are computed as shown below; otherwise, there are not enough aircraft of type NA to carry all the weapons in priority class N. The aircraft available among all weapons $i \in P$ are distributed in direct proportion to the number of weapons they have available for assignment; i.e.,

$$ACI_{NA,i} = ACI_{NA,i} * \frac{ACNUM_{NA}}{ACN_{NA,N}} \tag{32}$$

and similarly for $\ell \epsilon L_i$. $ACI_{NA,i}$ is distributed among its locations in direct proportion to the number of rounds the location contributed to the total; i.e.,

$$ACL_{NA,\ell} = ACI_{NA,i} * \frac{ACROH_{\ell}}{Total_i} \quad \ell \epsilon L_i, \; i \epsilon P_N \tag{33}$$

This has the advantage of keeping the fraction of aircraft assigned to a location in the same proportion as all other locatins with the same type. Consequently,

$$F_{NA,i} = ACL_{NA,\ell}/BATL_{\ell} \quad \text{for any } \ell \epsilon L_i \tag{34}$$

where $BATL_{\ell}$ is defined as the total number of aircraft of all types assigned to location ℓ; i.e.,

$$BATL_{\ell} = \sum_{NA=1}^{NACT} ACL_{NA,\ell} \quad \text{for each } \ell \epsilon L_i \tag{35}$$

where NACT is the number of aircraft types.

The procedure for calculating $F_{NA,i}$ is repeated until either all available rounds in each priority class have been assigned aircraft or all available aircraft have been assigned. The final value for $F_{NA,i}$ is then used to update the variable values for BL, CEP, DTW, PL, PSIK, PSPK, PTP, RF, WDF, WPRMN and WPRMX used in the allocation.

The procedure for updating the variables is to take the weighted average of the aircraft counterpart variables. For example, the aircraft counterpart for PL_i is PLA_{NA}, so the value used for PL_i is

$$PL_i = \sum_{NA=1}^{NACT} F_{NA,i} * PL_{NA} \tag{36}$$

Similar calculations are made for the other variables. Note that the aircraft counterpart for BL_i is $ACLOAD_{NA,i}$.

The procedure for updating the weapon delay time, $DTW_{i,1}$ and $DTW_{i,2}$, is done in a different manner as follows:

$$DTW_{i,1} = MIN(DTW_{NA,1}) \tag{37}$$

$$DTW_{i,2} = MAX(DTW_{NA,2})$$

where NA = 1,...,NACT and $F_{NA,i} > 0$

The reason for this change in procedure concerns itself with the use of DTW wherever IDTW = 1; in fact, IDTW must equal 1 for air loading to be used. $DTW_{i,1}$ and $DTW_{i,2}$ and DTT_j are used to compute a probability that target j's persistance time is greater than weapon type i's time to fire, or in the case of aircraft, time to arrive. This same calculation is made for each aircraft type that is used.

$$PPDMA_{NA,j} = \frac{e^{-\lambda T_1} - e^{-\lambda T_2}}{\lambda(T_2 - T_1)} \tag{38}$$

where

$$\lambda = 1/DTT_j$$

$$T_1 = DTW_{NA,1}$$

$$T_2 = DTW_{NA,2}$$

Then the probability that target type j's persistence time will be greater than the composite weapon type i, i.e., the weapon type i with multiple aircraft assigned, is given as follows using the weighted average scheme given above:

$$PPDM_{i,j} = \sum_{NA=1}^{NACT} F_{NA,i} * PPDMA_{NA,j} \tag{39}$$

Although the updated CEP function is noted as being the weighted average of the CEP functions of the aircraft assigned to that location, its actual use is more complicated. A more accurate representation of the effective CEP value is obtained by taking the weighted average of the CEP values of each aircraft assigned to a weapon type with respect to each target location. That is, CEP as input by the user defines a CEP function based upon weapon/target range. For each target, the value of CEP is calculated for each aircraft type assigned to that weapon type. These values are then weight averaged to find a composite CEP for the weapon/target range involved. This composite CEP is then used in the normal fashion.

Armed Reconnaissance Aircraft: The methodology implemented for modeling armed reconnaissance flights treats an armed recce location the same as any other weapon location with the following exceptions:

(1) Each armed recce location is implemented as two weapon launch points. The weapons available to be fired are split between the sites according to the fractional value input by the user for each location. This effectively reduced the maximum number of launch points available to be used to NWLPM-NARLF.

(2) An additional range check is made for armed recce locations, effectively restricting attacks to those targets within a band across the target area. This band width and location are controlled by the user.

(3) All armed recce weapons are assumed to acquire their targets with no location uncertainty.

(4) Regardless of the value of IDTW, the persistence time of a target is always assumed greater than the time to fire. Effectively, no DTW, DTT comparison is made.

Loiter Point Aircraft: UNICORN provides the user with a means of modeling loiter point aircraft. Weapon type and fraction of force on loiter are specified by the user. These are then combined with those user inputs that restrict launch point/target combinations to compute a fractional modifier of the $DTW_{i,1}$ value. This modified $DTW_{i,1}$ is then used to recompute the probability that target persistence time is greater than aircraft arrival time. The rational behind this approach derives from the most important reason for using loiter point aircraft - the fact that they enable quicker response time than conventionally based aircraft. This quickened response time has the effect of increasing the probability that a target, especially a highly mobile target, will be in place at aircraft arrival.

A non trivial problem, however, centers around the choice of the fractional modifier of minimum weapon delay $DTW_{i,1}$. Assuming that a loiter point will be close to the FEBA, a reasonable estimate of the fractional in flight time saving realized by using a loiter point aircraft from launch point i to attack target location j is

$$f_{i,j} = Y_i/(Y_i + Y_j) \tag{40}$$

where Y_i and Y_j are the respective distances from the FEBA. This fraction is location/target location dependent. For computational and storage reasons it is more convenient to have this value as a weapon type/target type parameter. To this end, the following sets are defined

$A = \{i \mid i \text{ is a weapon type assigned to loiter status}\}$

$K_i = \{k \mid k \text{ is a weapon launch point with weapon type } i \text{ such that } i \in A\}$ for each i

$T = \{j \mid j \text{ is a defined target type}\}$

$L_j = \{\ell \mid \ell \text{ is a target location with target type } j \text{ such that } j \in T\}$ for each j.

The probability then that a loiter point weapon of type i at launch point k will attack a target of type j at location ℓ is given by the joint probability

$$P_{k,\ell} = \frac{WPN_k}{WPTOT_i} * \frac{TGT_\ell}{TGTOT_j} \tag{41}$$

where

WPN_k = number of weapons at k assigned to loiter

$WPTOT_i$ = total weapons of type i on loiter that can attack ℓ

TGT_ℓ = number of targets at ℓ that were acquired

$TGTOT_j$ = total targets of type j acquired that can be engaged by i.

The above, of course, assumes that it is equally likely to choose any $k \epsilon K_i$ and any $\ell \epsilon L_j$. There are some instances, however, when $P_{k,\ell} = 0$, e.g., when ℓ is outside the effective range of k. Realizing this, then the effective fractional modifier of $DTW_{i,1}$ can be found for each target type j by

$$F_{i,j} = \frac{\sum_{\ell \epsilon L_j} \left(\sum_{k \epsilon K_i} \frac{WPN_k * f_{k,\ell}}{WPTOT_i} \right) TGT_\ell}{TGTOT_j} \qquad (42)$$

Given that the above fraction represents the probable time savings associated with choosing a loiter point aircraft with weapon type i to attack a target of type j, its effect on the probability that the aircraft will arrive before the target flees is calculated as follows. The probability (PPDM) that target persistence time is greater than aircraft time of arrival is computed by

$$PPDM_{i,j} = \frac{e^{-\lambda T_1} - e^{-\lambda T_2}}{\lambda(T_2 - T_1)} * (1 - FL_i) + \frac{e^{-\lambda T_1'} - e^{-\lambda T_2}}{\lambda(T_2 - T_1')} * FL_i \qquad (43)$$

where

FL_i = fraction of weapon type i assigned to loiter

T_1' = $F_{i,j} * DTW_{i,1}$

T_1 = $DTW_{i,1}$

T_2 = $DTW_{i,2}$

λ = $1/DTT_j$

Except for the above, loiter point weapon types are used identically to all other weapon types.

Collateral Damage: Two methods of collateral damage modeling are employed in UNICORN. The methods are designed to bound and/or assess damage to civilian populations or structures in the general scenario area which are not targets. Neither method addresses the concept of complementary damage to other military targets as a result of strategies carried out against any target. Only the collateral effects of nuclear weapons are considered.

In the first method of limiting collateral damage, the user may limit civilian casualties due to nuclear weapons by imposing a bounding constraint on the total number of expected civilian casualties. Each target location is permitted a single coded description which defines the local civilian population density and a vulnerability class. A set of curve fits to civilian casualties as a function of yield are employed. These were derived from reference 5. Alternate energy distribution weapons are assumed to produce collateral damage as if the weapon yield were the maximum of the blast, thermal and radiation equivalent yields. Each strategy utilizing nuclear weapons will contain an entry assessing civilian casualties. Every linear combination of these strategies is then constrained to be less than a user-specified amount. If the user does not specify such an amount the model assumes that civilian casualties are not to be considered and no such constraint is implemented, nor do the nuclear strategies contain the civilian casualty estimates.

A useful technique in certain study approaches is to declare a civilian casualty limit at a high, non-binding level. In this case, the model will assess total casualties, but not constrain the optimal allocation.

In the second form of modeling collateral damage, the user may limit the level of blast, radiation and thermal effects at user-specified scenario locations. The user specifies a maximum allowed blast, cumulative radiation, and thermal effect at each location. The blast effect is the peak overpressure in psi at the point from any individual target attack, the thermal effect is the peak calories per cm^2, and the radiation effect is the linear sum in rads of the radiation levels from all target attacks.

The estimated collateral radiation dosage at a point is a function of the distance from the point to the location of the weapon detonation, and of the weapon yield. Since errors in the delivery system may cause a random error about the intended burst location, some allowance for delivery errors must be made in the calculation of the value of radiation level. A routine has been developed which computes the expected radiation at a designated range from the weapon aimpoint, as a function of the weapon CEP. The error is assumed to be Gaussian with zero mean.

Previous analyses have yielded a functional form for evaluating the far-field prompt radiation level at a point, assuming negligible error in weapon explosion point. This value is a function of the weapon yield "y" and the offset distance "D". The functional form is given by

$$R(D) = \frac{A * y}{D^2} * e^{-D/B} + \frac{C * y}{D^2} * e^{-D/G} \tag{44}$$

The constants A, B, C and G are all functions of the type of weapon. This functional form fits closely to the data generated in the analysis which was performed to develop the technique for including weapon impact errors.

The model for the analysis is shown in figure 9. A weapon aimpoint is specified to be some distance "R" away from the point "P" of interest. The impact will occur somewhere around the aimpoint, perhaps at point x, as specified by the Gaussian impact distribution defined by the weapon CEP. The expected value of the radiation at point P is given by

$$E \text{ (Done at P)} = \iint_{-\infty}^{-\infty} R\,(|D|) * N\,(o,\sigma)\; dx\; dy \tag{45}$$

where $N(o,\sigma)$ represents the Gaussian kernel. Unfortunately, this does not integrate to a closed form; however, an approximation is possible

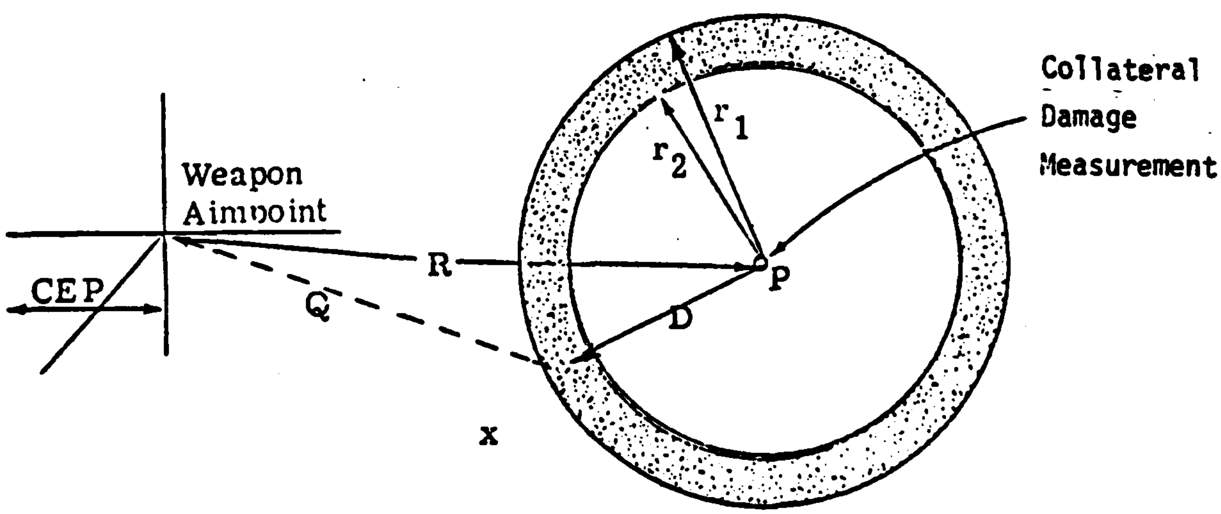


Figure 9. Collateral Radiation Damage Calculation at a Point

(Reference 11, pg. 931-934), by means of a formula for approximating the probability of impact of a Gaussian-defined distribution, within an offset circle. By approximating the above integral by a sum it is possible to arrive at a numerical solution for the expectation. The shaded area is an annulus of width $r_2 - r_1$. By the use of the formula for offset circles, the average probability of impact within the annulus is given as

$$Pr\ (r_2 + r_1/2) = Pr(r_2) - Pr(r_1) \qquad (46)$$

The use of the radiation formula will produce the expected radiation from that annulus:

$$E(R(r_2 + r_1)/2) = R((r_2 + r_1)/2) * (Pr(r_2) - Pr(r_1)) \qquad (47)$$

By summing over a large number of the concentric annuli of a given width about P the expected value is arrived at.

$$E(r) = \sum_{i=0}^{M} \left(R \quad (r_i + r_{i+1})/2\right) * \left(Pr(r_{i+1}) - Pr(r_i)\right) \qquad (48)$$

This formulation was used to generate data for a wide range of yields and CEPs. The data was then curve-fitted and the results incorporated into a subroutine. The routine linearly interpolates for the expected radiation when the input values do not coincide with the curve-fitted parametric values.

This value of expected collateral radiation is used as an entry in a linear program constraint. There is such a constraint for each point at which nuclear effects are to be limited. However the expected radiation is an estimate of the radiation at a particular point. As such, it may not be representative of damage over a large area. There may be a significant gradient to the prompt radiation as a function of range. A result is that, while one side of a large area may be at an excessive radiation level the other side may not. The user may represent such an area by defining a set of points which circumscribe the area.

Blast and thermal effects limitation is performed internal to the mathematical programming algorithm by checking each assignment as it is considered, to determine if it exceeds the specified peak overpressure or peak calorie/cm^2 at any limitation point. If so, the assignment is not allowed.

Military Collateral Damage: A post allocation assessment of military collateral damage is available in UNICORN. The concepts key to this evaluation are discussed below and include:

- Compatibility of damage criteria between collateral assessment and the weapons allocation.
- Precise spatial dispersion of targets and assignments of attack strategies to specific targets at a location.
- Definition of multi-weapon aimpoints.
- Collateral damage evaluation methodology.
- Limitations of the collateral damage assessment model.

Expected Damage Calculations: Throughout the collateral assessment, UNICORN calculates expected damage. This approach facilitates evaluation of damage from multiple aimpoints. The damage effects of two weapons on a target, whether both produce collateral damage or one primary and the other collateral, are calculated independently in a probabalistic sense, i.e.,

$$\text{DAMAGE} = 1 - (1 - \text{DAM}(I))\,(1 - \text{DAM}(J)) \qquad (49)$$

where DAM(I) is the damage inflicted by weapon I and DAM(J) that done by weapon J. If the original weapon allocation were carried out using a criteria other than expected damage, such as a 90% confidence of 30% coverage, the primary damage is recomputed using the same allocation but using an expected damage criteria. However, a count of targets sustaining overall damage exceeding a specified level is available by use of the input variable DE.

Target Dispersal and Strategy Assignment to Specific Targets: Multiple targets may be aggregated at a single location to facilitate the UNICORN user in his handling of a large data base. To correctly assess collateral damage to such targets the user may specify the rectangular pattern (input variable IRECXY to position the targets more accurately. Since the weapons allocation does not distinguish between collocated targets, a heuristic procedure assigns strategies if all targets at the location are not attacked by the same strategy.

An algorithm which approximates optimal assignment of weapons within the target location is used:

(1) Sort strategies against a single target location involving nuclear weapons in order of descending lethal radius.

(2) If two strategies have the same lethal radius, rank the strategy involving more weapons higher.

(3) Calculate all damage, both primary and collateral, that would accrue to the targets in the location if the next strategy in the sorted list were assigned to each of the remaining eligible targets.

(4) Assign the strategy to the target which would result in greatest total damage and declare the target ineligible for attack by further strategies.

(5) Reduce the remaining target values of all effected targets by the change caused by this strategy.

Iterate through steps 3 - 5 until all nuclear strategies are assigned to individual targets.

(6) Sort strategies involving non-nuclear weapons according to primary damage done, from most to least.

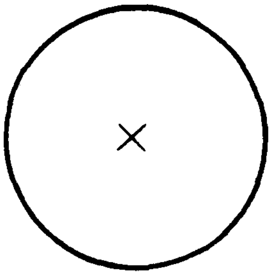
(7) Sort the eligible targets accor'ing to decreasing undamaged target value.

(8) Assign the strategies as sorted in step 6 to the targets as sorted in step 7.

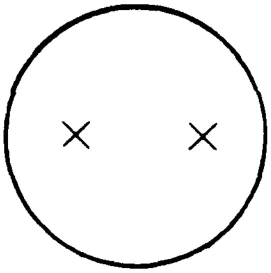
A simplified collateral damage scheme is used in this algorithm. The salient features include:

- Zero CEP
- "Cookie cutter" damage evaluation with triangular approximations to lethal area/target area overlap.
- Aimpoints assigned as described later.

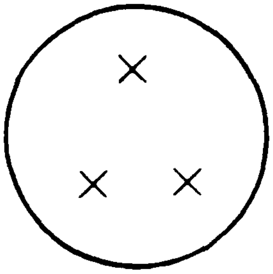
Aimpoint Assignment: The assessment involves a simple scheme for distributing aimpoints of multi-weapon strategies. A maximum of seven distinct aimpoints can be defined at a single area target. The patterns indicated in figure 10 are used depending on the number of weapons in the strategy. If seven or more weapons are involved, the pattern indicated in figure 10g is traced in sequence until all weapons have been assigned aimpoints.



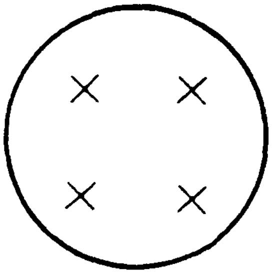
Pattern for
1 Weapon
(a)



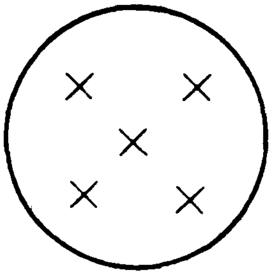
Pattern for
2 Weapons
(b)



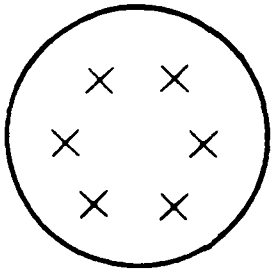
Pattern for
3 Weapons
(c)



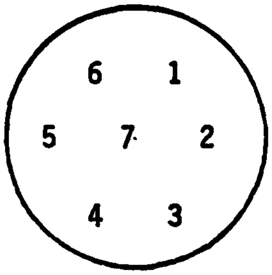
Pattern for
4 Weapons
(d)



Pattern for
5 Weapons
(e)



Pattern for
6 Weapons
(f)



Pattern for 7
or More Weapons
(g)

Figure 10. Military Collateral Damage Assignment

Collateral Damage Evaluation: The method of calculating collateral damage described in the section on strategy assignments is used only to decide on assignment of strategies. All final calculations employ a more detailed scheme. For each target to be evaluated for collateral damage from a weapon of lethal radius LR, the radii of two circles (see figure 11) are calculated by

$$R_{min} = \text{Minimum} \ \{TR + LR, DAP + 3 \ CEP\} \qquad (50)$$

$$R_{max} = \text{Maximum} \ \{|LR - TR|, DAP - 3 \ CEP\}$$

where

TR = target radius of secondary target
DAP = distance from aimpoint to center of secondary target.

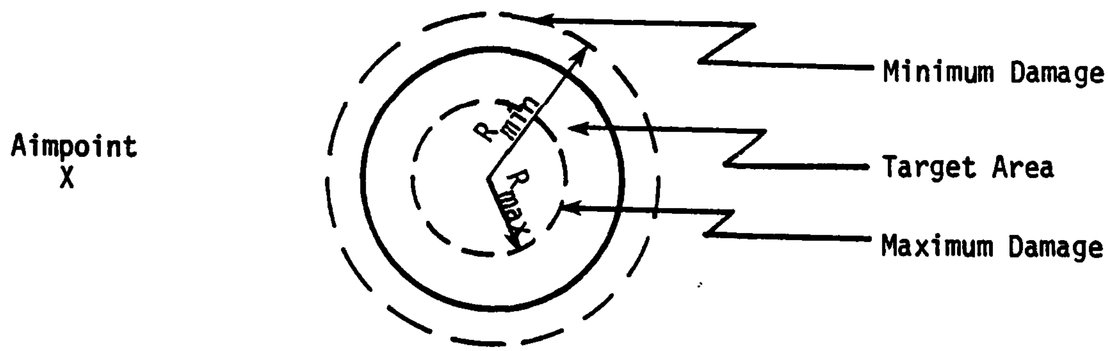


Figure 11. Maximum and Minimum Collateral Damage Circles

The CEP used is that of the weapon about its aimpoint. The minimum damage radius, R_{min}, is defined so that either the probability of a weapon impacting outside the minimum damage cirlce is negligible or any such weapon inflicts no collateral damage. Similarly either the probability of landing within the maximum damage circle is insignificant or the maximum possible damage will be inflicted anywhere wthin the circle.

A series of circles are then inscribed at equidistant intervals between the maximum and minimum damage circles defining a set of annular regions as in figure 12.

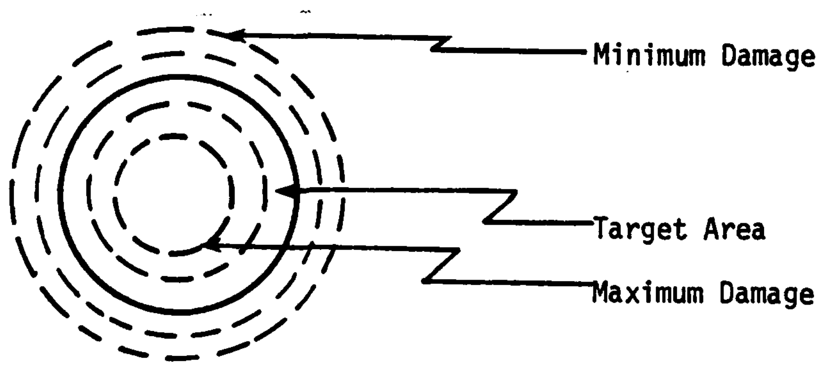


Figure 12. Definition of Annular Regions for Collateral Damage Assessment

The total number of circles, N, is determined by three factors: the damage done by a weapon impacting on the minimum damage circle (DAM_N); the damage done by a weapon impacting on the maximum damage circle (DAM_1); and the input variable PC.

$$N = (DAM_N - DAM_1)/PC \qquad 2 \leq N \leq 20 \tag{51}$$

For each circle of radius R_i ($i = 1,\ldots,N$), the damage, DAM_i, done to the secondary target from a weapon impacting a distance R_i from the target center and the probability, P_i, that a weapon will land within the circle are computed.

The total collateral damage is then

$$D = \sum_{i=1}^{n} \left[(DAM_{i+1} + DAM_i) * (P_{i+1} - P_i)/2 \right] + DAM_1 * P_1 \tag{52}$$

P_i is the integral of a circular normal distribution over an offset circle (target area) with radius R_i a distance RAP_i from the mean (aimpoint) of the distribution. Define $R = R_i/\sigma$ and $r = RAP_i/\sigma$ where the parameter $\sigma = .84932 * CEP$. Then P_i can be approximated (see reference 11, page 940) as

$$P_i = \begin{cases} \dfrac{2R^2}{4+R^2} * \exp\left(-2r^2/(4+R^2)\right) & R < 1 \\ P(x_1) & 5 > R > 1 \\ P(x_2) & R > 5 \end{cases} \tag{53}$$

where

$$x_1 = \frac{\left[R^2/(2+r^2)\right]^{1/3} - \left[1 - \frac{2}{9}\,\frac{2+2r^2}{(2+r^2)^2}\right]}{\left[\frac{2}{9}\,\frac{2+2r^2}{(2+r^2)^2}\right]^{1/2}}$$

$$x_2 = R\sqrt{r^2 - 1}$$

$$P(x) = 1 - \frac{1}{2}\left(1 + c_1 x + c_2 x^2 + c_3 x^3 + c_4 x^4\right)^{-4} + \varepsilon(x)$$

$$|\varepsilon(x)| < 2.5 \times 10^{-4} \tag{54}$$

c_1 = .196854

c_2 = .115194

c_3 = .000344

c_4 = .019527

The calculations involved in computing collateral damage at a single target from a single weapon are extensive. They can quickly become prohibitive for the number of targets and weapons used in a model the size of UNICORN.

A series of sieves screen out candidate weapon/target and primary/secondary target combinations. Discussion of TLCEP and TGTCEP in the UNICORN User's Manual (reference 1) should be consulted.

Limitations: Collateral assessment does not consider the following types of weapons and targets:

- Non-nuclear weapons.
- Earth penetrating weapons.
- Targets designated for cratering attack.
- Targets defined as linear.

Time Varying Relationships and Physical Characteristics

UNICORN is capable of representing selected effects of the passage of time on a battlefield. Among the model variabilities are rate of fire considerations, arsenal limits, preallocation losses, loss rates during allocation, C^3 effects, and target acquisition variations with range and time. The model operates on a time line as illustrated in figure 13.

A maximum available arsenal is specified by the user. Losses to this arsenal may be assessed in two manners. Prior to allocation in this scenario, losses to the arsenal may occur, perhaps through surprise attack or as a result of previous conflict. These losses reduce the arsenal to a level from which potential allocation may be made. During the scenario allocation weapons are expended, and they are also lost due to attrition. The loss rate function is illustrated as a decreasing arsenal level after the allocation initiation point.

The number of targets by type/location for which there is opportunity to fire (acquisition is current while release authority exists) is modeled as an increasing function over the allocation period, and these are referred to as available targets. The model assumes continuous

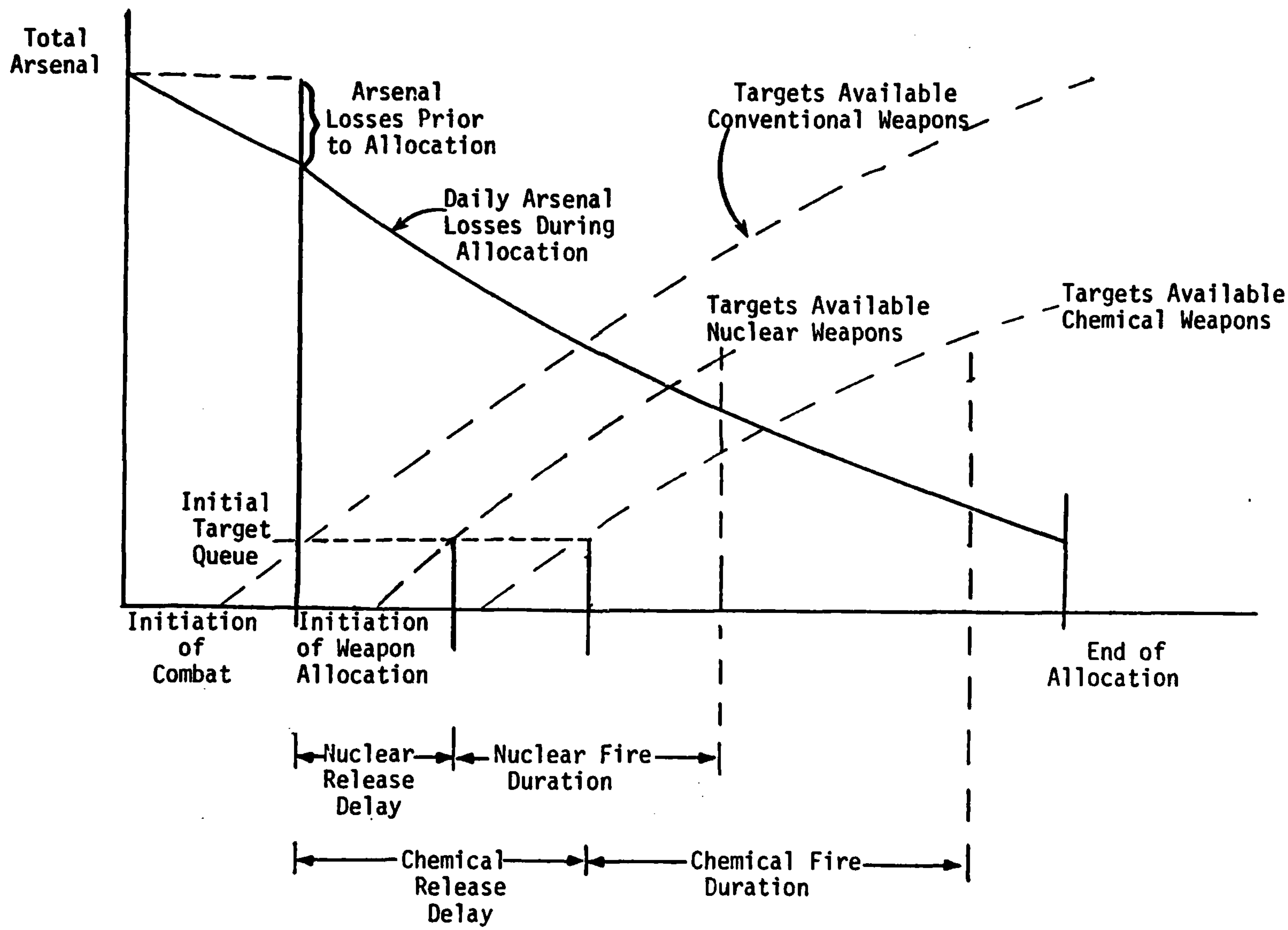


Figure 13. UNICORN Time Line

release authority for conventional weapons, so all targets acquired are available to conventional weapons. Of course the eligible weapons must satisfy range and C^3 constraints. Target acquisition is viewed as providing targets to a queue which is processed to assign weapons to those targets. The model permits the user to control the size of the starting target queue by indicating an amount of "previous knowledge" about targets.

The user may specify a delay in nuclear release permission and chemical release permission after start of the allocation. In effect, these delays limit the target availability for the related weapon lethality classes. A complementary effect is included which limits the available related weapons to those which could be expended in the period in which permission is granted. Figure 13 illustrates a case in which nuclear fire is permitted for a limited duration, and overlaps the allowed chemical fire duration period. Limited targets will be available for each kind of firepower. The problem is additionally complicated by the time overlap of the three weapon classes. There are as many weapon availability functions as there are distinct weapon launch points, in order to maintain the identity of effects relating to location dependent loss rates and initial arsenal size. Target availability is separately accounted for by target location with additional constraints placed on nuclear and chemical weapon strategies.

Weapon Availability: The number of weapons available to be allocated from a particular location is computed based on the rate of fire of the weapon type, the time available and the number of available warheads. Each launch point has an associated weapon allocation constraint in the linear program allocation. The total available weapons at the launch point may not be exceeded in the allocation. Each launch point is assumed to have the following associated variables:

- RF - rate of fire (per hour)
- BL - launchers (or A/C) per battery
- BATL - batteries per location
- RPL - rounds per launcher
- PL - probability of launch
- T - maximum time available for weapon allocation by this weapon type
- PLS - prelaunch survival probability (surviving fraction at beginning of allocation period).

Each launcher is assumed capable of independent fire at a rate defined by RF, thus the maximum number of launch reliable weapons (WPN) is given by

$$WPN = \min \begin{cases} (RF)(BL)(BATL)(T)(PL)(PLS) \\ (RPL)(BL)(BATL)(PL)(PLS) \end{cases} \quad (55)$$

Note: The model permits the user the option to instead include the prelaunch survival and launch reliabilities as weapon reliability modifiers in construction of the damage function. This approach more nearly represents the effect of carrying out an allocation under a previously generated war plan. Generally, such war plans do not permit responsive reassignment of weapons to account for launch failures or weapon loss prior to launch. This situation is not usually considered to occur in tactical weapon use.

The rate of fire may be modified under some conditions. If the switch ISURGE = 1 or 3, the value for rate of fire is internally compared with the value for the weapon response time DTW and the resulting value RF is used in the computation of allocatable rounds. The modified RF is determined by

$$RF = 1/\max \begin{cases} 1./RF & \\ DTW_1 & IDTW = 0 \\ DTW_1 + DTW_2 & \text{for a/c, when } IDTW = 1 \\ DTW_2 & \text{for non a/c, when } IDTW = 1 \end{cases} \quad (56)$$

where

DTW_1 = minimum time to fire (time from maximum preparation without target information) of the weapon

DTW_2 = maximum time for preparation to fire of the weapon

IDTW = switch to determine the method of calculating the probability that the target's persistence time will be greater than the weapon's time to fire.

Additionally, UNICORN permits the user to give launchers an additional rate of fire capability associated with their state of preparedness at authorization of fires time. If they are in a state of maximum readiness at the start of fires time (ISURGE = 2 or 3) and the minimum time for the launcher to fire (DTW_1) is less than or equal to the total time allowed for firing weapons of that weapon class (T), then the rate of fire value used in the allocatable round calculation (eq. (32)) is given by

$$RF = RF + \frac{1}{T} \quad (57)$$

The number of available weapons (WPN, from eq. (55)) is then modified to include the effect of loss during the allocation and the effect of limited duration of allocation by weapon class. All weapon losses are assumed to be of a random nature. The expected survival level is assumed to be defined by time t, and daily loss rate DL, thus an average weapon level in the interval (t_1, t_2) is modeled as

$$\overline{WPN} = \int_{t_1}^{t_2} \frac{WPN\ (1 - DL)^{t/24}}{(t_2 - t_1)}\, dt \tag{58}$$

where t_1 and t_2 are measured relative to the initiation of weapon allocation (figure 13).

The allocation process will generally allocate all available weapons. However, in certain cases, the allocation can be instructed to save weapons provided certain minimal criteria are satisfied. This may result in weapons surviving after the allocation despite usage and intervening losses. These values could provide the basis for a stepped sequence of allocations. The model has implemented a survivability concept concerning weapons and their launches. It assumes that of those rounds not utilized in the allocation itself, only rounds associated with surviving launchers may be considered to have survived. The surviving launchers at a location are estimated to be

$$SURLN = (BL)(BATL)(1 - DL)^{TMX/24}(PLS) \tag{59}$$

where

- BL = launchers per battery
- BATL = batteries at the location
- DL = daily loss rate
- TMX - time interval between start and end of weapon allocation (figure 13)
- PLS = prelaunch survival probability
  NOTE: This value is only included if PLS is treated as a reprogrammable reliability, as in eq. (55)

The number of surviving rounds per launcher are then computed from

$$SURRPL = RPL - (\min(RPL, TT \cdot RF))(SW) \tag{60}$$

where

$$SW = \frac{\overline{WPN} - RNA}{\overline{WPN} + RNE}$$

where

RPL = rounds per launcher
TT = time available (for this weapon type) to fire
RF = rate of fire
$\overline{WPN}$ = see eq. (58)
RNA = rounds not allocated of those eligible to be fired from this location
RNE = rounds not eligible to be fired from this location.

Given the estimates of eq. (59) and (60), the total number of surviving rounds is estimated as

$$SURRND = SURRPL*SURLN \tag{61}$$

The surviving batteries per location value is computed from

$$SURBAT = BATL(1 - DL)^{TMX/24}PLS \tag{62}$$

as in eq. (59). These values will permit the user to step through a time sequence of weapon allocations, provided constraints are imposed at each step which limit the number of weapons to be allocated. The targets available at the end of each step are computed internally but are simply the number not destroyed. That is

$$TGTN_i(J) = TGTN_{i-1}(J) - D_i(J) \tag{63}$$

where

$TGTN_i(J)$ = the number of targets at location J at the end of the ith step, and

$D_i(J)$ = the number destroyed in the ith step.

Target Acquisition: Each target location has an associated number of targets (TGTN) which represents the number of targets of that type in the vicinity. It could represent a single target or class of targets in a range band. The model permits the user to represent effects of time and distance behind the FEBA in target acquisition, as well as the effects of previous knowledge about target location prior to start of allocation. These variabilities are all implemented through an expected value process modeling the random process of target acquisition.

The acquisition process is viewed as an accumulation of opportunities to fire. Equivalently, as targets are acquired, they are evaluated and the preferred targets are fired on. This presupposes that the battlefield weapon coordination net can assign eligible weapons to targets prior to the time at which target track would be lost. This is modeled by a probability that persistence time of a target exceeds the time to fire of an eligible weapon. The UNICORN model thus accumulates target opportunities over the entire interval of allocation. The accumulation functional form is given by

$$\overline{TGTN} = (TGTN)(1 - (1 - PAQ(R))^{(TT + queue/TAQ)} \qquad (64)$$

where

$\overline{TGTN}$ = total targets possible at a location

$PAQ(R)$, TAQ = probability of acquisition at distance R behind the FEBA, in time interval TAQ

TT = time available for target acquisition during weapon allocation

queue = used to determine the initial active target queue which is based on prior acquisition still effective at beginning of allocation

PREVK = fractional value representing previous knowledge

DTT = expected target persistence time.

The model permits the acquisition function to be curve fit by a two parameter fit. PAQ and TAQ may represent an actual single pass acquisition probability at intervals of TAQ or they may represent an average acquisition probability over any interval. Figure 14 illustrates how the acquisition probability may represent variation with distance behind the FEBA. Three (PAQ, range) value pairs are specified. These values are curve fit by the equation

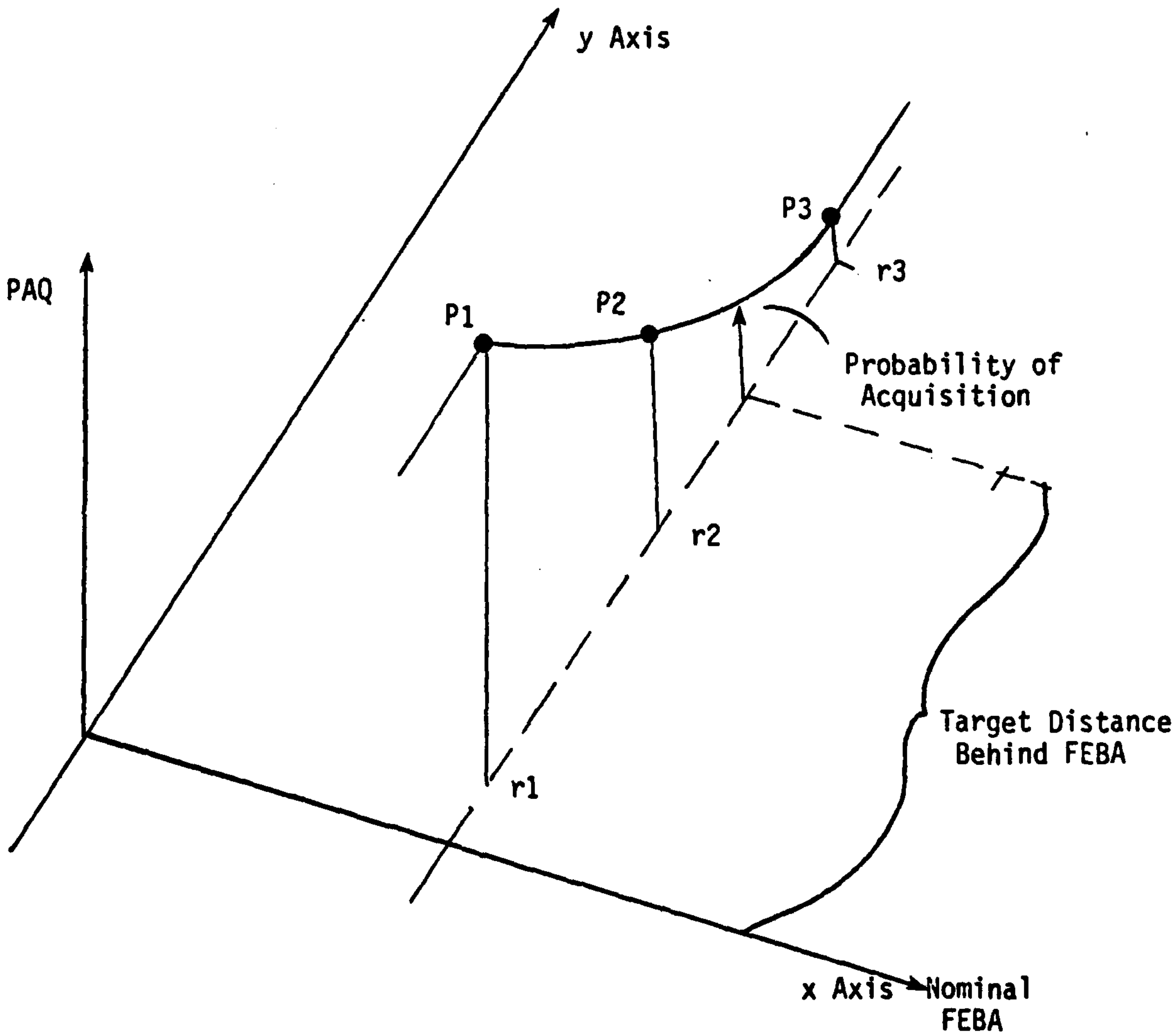


Figure 14. Range Dependent Probability of Acquisition

$$PAQ(r) = a + b(1 - Q^{(r - r_1)/(r_3 - r_1)}) \qquad r_1 \leq r \leq r_3 \qquad (65)$$

$$PAQ(r) = P_1 \qquad r < r_1$$

$$PAQ(r) = P_3 \qquad r > r_3$$

Each target location has a defined distance behind the FEBA, thus the acquisition probability function equation (64) represents variability by location.

Each target type has an associated variable which represents the target persistence time (DTT). This variable may be used to represent fixed targets, by specifying DTT to be a large number. For mobile targets DTT should represent the expected amount of time available to deliver a weapon against the target, before it is lost from the target list. This variable is also instrumental in determining the expected number of targets at a location which are in the target queue prior to start of allocation. The initial target queue may represent the peacetime target acquisition, or a different level of surveillance resources.

Reference to eq. (64) shows that the initial target queue is given by setting TT equal to zero. The value for "queue" represents the observation interval prior to the initiation of weapon allocation during which any targets acquired will remain current into the allocation period. If the previous knowledge value (PREVK) is 1 or less, it acts on target persistence time to produce "queue" = (PREVK) (DTT) for each target type. If PREVK > 1, then "queue" = PREVK for all targets.

The variable TT is interpreted as the time available for target acquisition during weapon allocation. This value varies by weapon class (conventional, nuclear or chemical) as illustrated in figure 13. It is a function of weapon class release authority and duration of allowed fire. Targets are assumed to be attacked shortly after becoming available. The implementation actually carries out one alloation of weapons against the accumulated target level, by weapon class. This is equivalent to the average effect of allocation in acquisition sequence. However, the model may have accumulated lists of targets for two or more weapon classes in which the expected number of targets available per class differs due to different lengths of observation (TT). Due to the representation of these target lists in UNICORN the allocation tableau might permit the targeting of more low acquisition likelihood targets by a weapon class than would actually be possible for that class. This possibility is restricted by defining that all targets be accumulated for a single weapon class. (If conventional weapons are in the scenario then they are this class.) A set of constraint rows, one for each target location is included for this class (e.g., for each target type/location). If nuclear weapons are also in the scenario but have an authorized firing time less than the total planning time, then a constraint limiting the total number of targets for nuclear weapons is included, along with an additional constraint limiting nuclear attacks against "low acquisition likelihood" targets. Targets are considered in this category if the acquisition probability in a three hour interval is less than .5. That is

$$1 - (1 - PAQ(r))^{3/TAQ} \leq .5 \tag{66}$$

A similar set of constraints is defined for targets eligible for chemical attack. These four constraints along with the target row constraints generally eliminate the excessive targeting of low likelihood targets.

Target Persistence Time vs. Weapon Delay Time: The model allows the user the option of modeling target persistence time and weapon delay time as either fixed lengths of time or as random variables distributed in time. If modeled as random variables, target persistence time is modeled as exponentially distributed and weapon delay time as uniformly distributed. This information is used in determining the probability that the persistence time of a target exceeds the time to fire of an eligible weapon.

This is accomplished in UNICORN in the following manner. Let

PT = persistence time of a target

TTF = time to fire of an associated weapon

DTW_1 = minimum time to fire (time from maximum preparation without target information) of the weapon

DTW_2 = maximum time for preparation to fire of the weapon

DTT = mean persistence time, in an exponential distribution, of the target

IDTW = switch to determine the method of calculating the probability that the target's persistence time will be greater than the weapon's time to fire.

Then

$$
PR(PT > TTF) = \begin{cases} 0 & \text{if } IDTW = 0 \text{ or } DTW_1 \geq DTW_2 \text{ and } DTT < DTW_1 \\ 1 & \text{if } IDTW = 0 \text{ or } DTW_1 \geq DTW_2 \text{ and } DTT \geq DTW_1 \\ \dfrac{e^{-DTW_1/DTT} - e^{-DTW_2/DTT}}{(DTW_2 - DTW_1)/DTT} & \text{if } IDTW = 1 \text{ and } DTW_1 < DTW_2 \end{cases} \quad (67)
$$

This probability is then used to modify the damage function, as computed in eq. (16), if the weapon/target combination is eligible.

Weapon Launch Point/Target Location Eligibility: The UNICORN model considers every weapon location for potential attack against every target location. There is a variety of conditions which prohibit or limit the allocation of weapons from a particular location against a specified target location. Following is a list of these; a weapon allocation would be prohibited if any condition were violated.

- Range from the weapon location to the target is within the feasible range of the weapon type.
- This target is in the band for the armed recce weapon.
- Minimum weapon delay time is less than the allowed allocation time.
- Minimum weapon delay time is less than the target persistence time.
- Weapon delivery classification is eligible for attack on this target.
- Weapon launch point is eligible for attack on this target.
- Weapon lethality type is eligible for attack on this target.

Those controls which may limit a weapon strategy are

- Maximum nuclear yield against the target. If a smaller yield is not available then this control may prohibit an allocation.
- Number of nuclear weapons allowed against a target.
- Maximum number of weapons allocated from a launch point.
- Maximum nuclear damage against a collateral effects point.
- Maximum total damage against the target.
- Collateral effects limitations.
- Collateral casualty limitations.

UNICORN Allocation Process

The use of linear programming with column generation in strategic arms analyses (reference 11), and in commerical resource allocation problems (reference 12) is well known. The technique has been applied in the solution of the current UNICORN weapon allocation problem. The general formulation assumes that the problem can be stated as a maximization or minimization of a sum of functional values which are subject to a set of linear constraint equations. In the case of UNICORN, maximizing the total damage achieved against an opponent while satisfying constraints on the number of weapons, and other bounding constraints, satisfies the requisities for use of this procedure.

The previous discussion in this manual describes the procedures for the UNICORN problem as a mathematical program. The user specifies in some manner a value scale which assigns a total value to damage criteria satisfaction against a single target of each target type. The user also specifies the scenario variables, i.e., target locations, weapon locations and associated parameters as well as availability of weapon types. In addition, the user specifies the appropriate allocation control variables, e.g., allowed collateral radiation and blast at designated points, attack type per target type and required damage level of the appropriate target categories. The result is automatically formulated by the model into a mathematical programming tableau. The availability of weapon types creates "less than" constraints, one for each weapon location, with the right-hand-side indicating the available number of weapons. Each target location is represented by a single "less than" constraint. The required damage levels result in several "greater than" constraints. Each collateral effects point results in a single "less than" radiation constraint. A series of budgeting constraints is also present. These permit several options associated with "least cost" weapon allocation, where cost may be expressed in several commodities simultaneously (e.g., dollars, plutonium, etc.).

The problem structure is formalized as

$$\text{maximize } f(x) \tag{68}$$

$$\text{Subject to } A\,x \leq b$$

$$x \geq 0$$

By suitable adjustment of the function f and the constraint matrix, A, both equality and greater than constraint types can also be included.

Each column in the tableau represents an attack level from a single weapon location upon a single target. The value in the objective function is calculated for the particular attack level. Conceptually every possible attack strategy against every target could be created and placed side-by-side in the tableau, and then a linear program would pick the best set of columns to conform to the constraint set and maximize the objective function total. This is not feasible due to the number of weapon/target combinations. The procedure utilized in UNICORN is called column generation (reference 11) and is a means of implicitly examining all of the columns but only explicitly generating a fraction of them. A set of candidate strategies is used to start the process, and a standard linear program procedure solves that tableau. The best set of strategies are then saved. Using the information generated during the solution process, new strategies which could potentially improve the answer are identified. These are combined with the previous solution in a new tableau, and the process repeated until no new strategies could improve the current solution. The last solution thus obtained is optimal.

The UNICORN Tableau

The current LP tableau, in addition to constraints on the total number of weapons in the stockpile, includes several constraint rows which are intended to enforce user-specified preferences in the weapon allocation. These include required constraint level of targeted firepower and mobility, collateral radiation effects limits, collateral casualty limits, and specific representation of area SAM suppression requirements. Additional target specification involves the classification of each target location into one of several subtypes. These are user-specified by target location and are intended to partition the target set into a variety of user-specified classes. Targets may also be classified into categories by target type rather than location. Either or both of the target location subtype classifications and the target type category classifications may be explicitly represented by linear program constraints. Either classification method could be used to model requirements to tactical nuclear targeting procedures or political considerations. Weapon cost information may be included in the budget rows, or the user may cause various effects to be considered in the force structuring process by inputting other data such as the amount of plutonium in the warhead, or an expected survivability factor.

The actual tableau structure is depicted further in figure 15. The entries in the tableau are calculated or extracted from current data as each column is generated. The figure illustrates the variety of considerations which are possible in UNICORN. As can be seen in the figure, the number of rows of each type may vary from zero to some maximum number, except for weapon locations and target locations. These are required to have a minimum of one. The user defines the tableau structure by specifying the number of weapon locations, target locations, and the constraint types to be considered.

One of the advantages of the linear programming formulation is that the dual variables from the linear program at optimality give the sensitivity of the results to the constraints. One of these variables, λ_i indicates the sensitivity of the results to the number of weapons of type i in the arsenal. Hence, if $\lambda_i > \lambda_j$, weapon i is preferred to weapon j (all other constraints being equal). In the case of collateral radiation damage or warhead plutonium constraints, for example, λ_i would indicate the sensitivity of the results to the allowed collateral damage or the total plutonium stockpile.

Row Description	Number of Rows	Entry Description	Constraint	
			Type	Bound
Objective function	1	Value destroyed	=	None
Weapon launch point rows	1-50	Number of launch reliable weapons	≤	Total launch reliable weapons
Area SAM def. suppression	0-3	1 if target is an Area SAM	=	Fraction of Area SAM sites required to be attacked
Target firepower destruction/attack	0, 1	Firepower destroyed or attacked	≥	Required total firepower
Target mobility destruction/attack	0, 1	Mobility destroyed or attacked	≥	Required total mobility
Nuclear radiation at collateral point	0-10	Estimated radiation at collateral point	≤	Maximum cumulative radiation at point
Target subtype	0-10	1 if this target is in this subtype	≥	Required attack level in each subtype
Target category	0-10	1 if this target is in this category	≥	Required attack level in each category
Total nuclear warheads	0, 1	Entry in appropriate row by weapon class: Number of weapons required to support this assignment.	≤	Total nuclear warheads
Total chemical warheads	0, 1		≤	Total chemical warheads
Total conventional rounds	0, 1		≤	Total conventional rounds
Plutonium budget	0, 1	Amount of plutonium in weapons	≤	Total plutonium budget

Figure 15. UNICORN Linear Programming Tableau (Part 1 of 2)

Row Description	Number of Rows	Entry Description	Constraint Type	Constraint Bound
Dollar budget	0, 1	Dollar cost of weapons	$\leq$	Total dollar budget
Civilian collateral losses	0, 1	Expected number of civilian casualties	$\leq$	Maximum civilian casualties
Nuclear attack limit	0, 2	1 if a nuclear weapon	$\leq$	Total targets available for nuclear attack
Nuclear attack limit low target acquisition		entry if target has low acquisition likelihood	$\leq$	Total low likelihood targets for nuclear attack
Chemical attack limit	0, 2	1 if a chemical weapon	$\leq$	Total targets available for chemical attack
Chemical attack limit low target acquisition		entry if target has low acquisition likelihood	$\leq$	Total low likelihood targets for chemical attack
Required damage	0-3	Value destroyed for a specific subtype	$\geq$	Minimum required value destroyed
Target location rows	1-150	1 in appropriate row	$\leq$	Total acquired targets at location

Figure 15. (Part 2 of 2)

These variables, as well as a summary of the optimal allocation resulting under the user-specified constraints, are printed after optimality is reached. Care should be exercised in interpreting the dual variables values resulting from the UNICORN tableau. The magnitures are quite dependent on structure of the target value system and on the tableau makeup. The inclusion of "equality" constraints and "greater than" constraints also affect the λ values. Reference to any linear programming text or references 11 and 12 will provide a more complete interpretation of λ values than has been attempted herein.

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