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Modeling a Chemical Battlefield and the Resulting Effects in a Theater-Level Combat Model

Todd M. Gesling

MODELING A CHEMICAL BATTLEFIELD
AND THE RESULTING EFFECTS IN A
THEATER-LEVEL COMBAT MODEL

THESIS

Todd M. Gesling, Captain, USA

AFIT/GOA/ENS/97M-06

DEPARTMENT OF THE AIR FORCE
AIR UNIVERSITY
AIR FORCE INSTITUTE OF TECHNOLOGY

Wright-Patterson Air Force Base, Ohio

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STUDENT: Captain Todd M. Gesling CLASS: GOA-97M

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COMMITTEE	NAME/TITLE/DEPARTMENT	SIGNATURE
Advisor	Jack M. Kloeber, Jr., Lieutenant Colonel, USA Assistant Professor of Operations Research Department of Operational Sciences Air Force Institute of Technology	
Reader	John O. Miller, Major, USAF Assistant Professor of Operations Research Department of Operational Sciences Air Force Institute of Technology	
Reader	Mark A. Youngren, Lieutenant Colonel, USA Assistant Professor of Operations Research Department of Operations Research Naval Post-Graduate School	

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THESIS

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Todd M. Gesling, B.S.

Captain, USA

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Todd M. Gesling

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ABSTRACT

This thesis describes the development of a methodology to model chemical weapons use in the Joint Staff's Joint Warfare Analysis Experimental Prototype (JWAEP) and to quantify the resulting effects. The methodology incorporates organic unit assets and theater-level chemical assets into JWAEP by using the three principles of nuclear, biological, and chemical defense (NBC) which reflect joint and Army doctrine, and combines them with the basic concepts already used in existing theater-level models. Other aspects of the problem include representing chemical "packages" on the battlefield, determining attrition and time effects, adjusting unit effectiveness, determining chemical package intelligence acquisition procedures, identifying solution techniques, verifying the results, and making recommendations.

The proposed solution techniques provide a feasible methodology for integrating high resolution modeling into a low resolution model. The algorithms incorporate the chemical estimate process, Mission Oriented Protective Posture (MOPP) analysis, and employment of appropriate doctrinal unit tactics based on a perception of existing or potential chemical weapons use. Thus, the methodology provides accurate input into the JWAEP for approximating real world results as well as a structured and quantifiable framework reflecting joint and Army doctrine that can be used for stand alone chemical effects analysis.

MODELING A CHEMICAL BATTLEFIELD AND THE RESULTING EFFECTS IN A THEATER-LEVEL COMBAT MODEL

I. INTRODUCTION

1.1 Purpose and Background

"Whether or not gas will be employed in future wars is a matter of conjecture, but the effect is so deadly to the unprepared that we can never afford to neglect the question."

- Final Report of General John J. Pershing,
Commander-in-Chief
American Expeditionary Forces, 1920 [5: 1-1]

In the post-Cold War era, countries are no longer restrained by superpower interests and believe the idea that war is a legitimate means of resolving a conflict [15: 150]. The wide variety of potential conflicts requires that our Army must be capable of waging war under any condition, including those created by weapons of mass destruction. The Army's doctrine manual, FM 100-5, defines weapons of mass destruction as: "Weapons that through use or the threat of use can cause large-scale shifts in objectives, phases, and courses of action" [12: 6-10]. This definition requires that these types of weapons must produce long-lasting effects and/or cover large areas. Currently, there exist only three weapon types that meet these requirements: nuclear, biological, and chemical (NBC) [21: 4].

The number of countries possessing these weapon types continues to grow. The most prevalent and widely used weapon type is chemical with at least 24 countries confirmed or suspected of having an offensive chemical warfare program [21: 4]. The

Chemical Weapons Convention of 1993 bans the use of chemical weapons. Over 159 nations, including the United States, have signed this convention and 42 have ratified it [14: 30]. The United States is currently in the process of ratification of this convention, reaffirming a policy of no use in either first strike or retaliatory measures. However, several countries with offensive chemical capabilities such as North Korea have refused to sign [21: 4]. This refusal to sign coupled with traditional conventional capabilities presents a dynamic, asymmetric battlefield where the threat of chemical attack increases [18: I-3].

1.1.1 Chemical Unit Organization

Chemical units provide NBC reconnaissance, decontamination, and large area smoke. They are employed throughout the theater of operations to enhance the combat power of a maneuver force. Due to the variations in types of chemical units, their organization for combat is solely dependent upon their potential requirements and missions. Although these missions are equally important, the efforts of this thesis focus only upon chemical reconnaissance and decontamination. The basic organization for chemical units is the company. Appendix A lists the various types of chemical companies, their basis for allocation, their mission statements, and their number of critical assets such as decontamination apparatuses and reconnaissance vehicles. Although the exact numbers and types of units will vary, the command and control structure is generally the same. A possible organization of chemical units for a maneuver corps is represented in Figure 1.

Figure 1 depicts three different types of maneuver divisions: heavy, airborne or air assault, and light with their organic chemical unit assets. The units comprising the chemical brigade may operate in one of three command relationships in support of maneuver forces: assigned, attached, or operational control [5: 7-3-4].

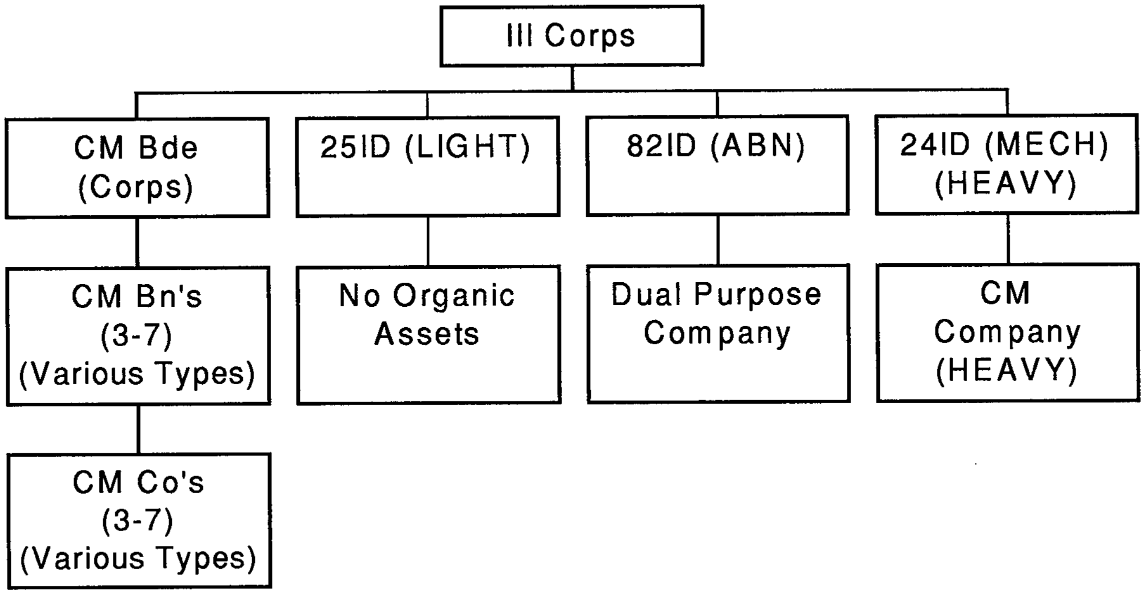

Figure 1 Chemical Unit Organization for Maneuver Corps

1.1.2 Model Background

The Joint Warfare Analysis Experimental Prototype (JWAEP) is a software simulation prototype developed by the Naval Postgraduate School in support of the research effort and evaluation aid Joint Stochastic Warfare Analysis Research (J-STOCHWAR). The JWAEP combines two sets of software previously developed for the Joint Staff, J-8: the Arc-Node Model (ANM) and the Future Theater-Level Model (FTLM) [17: 2; 31: 1]. The intent of J-STOCHWAR is to incorporate variability and uncertainty into a low resolution, highly aggregated theater-level model [30: 1-3].

1.1.3 Model Purpose

JWAEP is an interactive, two-sided, theater-level combat model based on an arc-node representation of ground, air, and littoral[1] combat [31: 1]. JWAEP differs from existing low resolution theater-level combat models by portraying decisions and resulting combat with uncertainty and variability rather than deterministically. It can be used in two different modes: interactive gaming or closed-form stochastic analysis.

In the interactive gaming mode, decision makers use the JWAEP model to analyze the outcomes of their decisions in a theater-level campaign. Included in the JWAEP model is the capability of analyzing measures of effectiveness (MOEs) at critical events and analyzing the outcomes of major sequences of events during the simulation run [23: 17]. The interactive command and control (C^2) allows the man-in-the-loop decision maker to make decisions based upon perceptions of the enemy derived through the command, control, communications, and intelligence (C^3I) process. These perceptions are the basis for representing the stochastic nature of war.

In the closed-form stochastic analysis mode, analysts can answer questions relating to force structure, effects of existing and possible new equipment and weapon systems, and planning of campaign operations [23: 15].

1.2 Problem Definition and Research Objectives

Representing the use of chemical weapons and its subsequent effects in a combat

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[1] Littoral representations of naval and amphibious operations in JWAEP are pending.

model is difficult, complex, and missing in JWAEP. All of the major characteristics and factors influencing chemical weapon use and their effects must be determined and reflected in the logic and algorithms. Therefore, the overall problem definition can be stated as follows: *explicitly model chemical weapon use and its resulting effects in a manner that can be used in JWAEP while accommodating joint and Army doctrine.*

Since the use of chemical weapons on the battlefield can act as both force multiplier and degrader, an accurate representation of their use is essential. Therefore, the purpose of this thesis is to develop the logic and algorithms required to represent the use of chemical weapons and their resulting effects at an appropriate level of resolution in the theater-level combat model simulation Joint Warfare Analysis Experimental Prototype (JWAEP). Specifically, the objectives are:

(1) Investigate the logic for implementing and representing chemical weapon use on the battlefield.
(2) Develop the logic for implementation of unit protective postures.
(3) Develop the algorithms for degradation of effectiveness while in protective postures.
(4) Develop the algorithms for determining the time required to negotiate chemical hazards.
(5) Develop the algorithms for attrition when encountering chemical contamination.
(6) Investigate the logic required for detection and decontamination of chemical contamination.

1.3 Research Scope

The methodology for representing chemical weapons use on the battlefield and the resulting effects utilizes high resolution modeling incorporated within a low resolution model. By doing so, the modeling efforts may be applied to similar combat models of either resolution or developed as an independent chemical assessment tool. The methodology determines effects from the time of employment until the removal of the chemical hazard from the battlefield.

To develop the logic required to represent chemical weapons use and the resulting effects in JWAEP, research efforts encompassed the following areas: JWAEP model composition, Army doctrine concerning operations in a chemical battlefield environment, and the modeling of chemical weapons use effects in other relevant combat models.

The first area of research is JWAEP model composition. In order to develop the algorithms required to represent a chemical battlefield, a thorough understanding of the construction and qualities of the JWAEP model is required.

The second area of research includes an overview of Army doctrine as it pertains to operations under chemical conditions. The United States military relies on chemical defense to survive, fight, and win against enemy use of chemical weapons on the battlefield. The foundation for this defense is built on three principles: avoidance, protection, and decontamination [5: 4-0]. In order to gain any valid information or analysis useful to the decision maker, the model must represent the effects of actual combat as closely as possible [3: 5]. Thus, the algorithms and decision logic used in the model must reflect this doctrine to achieve acceptance as a valid representation of combat.

The final area of research involves an analysis of other relevant combat models. These models contain algorithms and decision logic that provide further insight into the modeling efforts required to portray a chemical battlefield in JWAEP. Although each model is conceptually different as to the representation of chemical weapons use and their effects, they can provide a basis from which to start developing the logic and algorithms required for the modeling of a chemical battlefield in JWAEP.

1.4 Overview

The following chapters contain the research, proposed methodology, results, recommendations and conclusions.

Chapter 2 contains information on the JWAEP model composition, Army chemical doctrine, and other combat models' treatment of chemical weapons use and effects. Chapter 3 contains the proposed methodology to explicitly model chemical weapons use and its resulting effects. Chapter 4 discusses and demonstrates the results, analysis, verification and validation of the methodology. Chapter 5 provides the recommendations and conclusions.

II. DISCUSSION OF LITERATURE

2.1 JWAEP Composition

Through a series of workshops on Simulation Taxonomy (SIMTAX), the Military Operations Research Society (MORS) developed a warfare simulation taxonomy which classifies these simulations according to three functionally related dimensions: purpose, construction, and qualities [2: 1-2]. The purpose of JWAEP was discussed previously in Chapter 1. Therefore, only the JWAEP construction and qualities are discussed here.

2.1.1 JWAEP Construction

The MORS workshop defined construction as the design of the model [2: 9]. Within the construction dimension, the workshop determined four essential categories that can be used to describe combat models: human participation, time processing, treatment of randomness, and sidedness [2: 9-11].

Human participation is the extent to which a human presence is allowed or required to influence the operation of the model [2: 9]. The extent of human participation in JWAEP varies dramatically depending on the mode in which the model is run. In the interactive gaming mode, JWAEP relies on the man-in-the-loop decision making. At various points in the simulation, the decision maker determines the appropriate action to take in support of his objectives based upon the perceptions developed and information obtained through JWAEP. In the closed-form stochastic analysis mode, the extent of human participation is relatively low. Prior to a simulation, analysts input the required data parameters in support of a simulation objective. The simulation is run uninterrupted until completion. Analysts then extract the desired data for analysis.

Time processing is an implicit methodology within a model that describes how the model treats changes in the status of resources over time [2: A-7]. The JWAEP model can be categorized as a dynamic model since it represents the passage of time through a continuously running clock. The user has the ability to specify the ratio of simulated time to clock time to meet the needs of the intended simulation [31: 9].

The treatment of randomness is the manner in which models treat random events or the possibility of various outcomes of the same event [2: 10, A-9]. Most theater-level combat models are deterministic. However, as stated earlier, JWAEP is the only existing theater-level model which explicitly deals with uncertainty and variability, classifying it as a stochastic model. The stochastic nature of JWAEP was based upon the following imperatives: (1) combat is stochastic, (2) many input values are unknown and unknowable, (3) operational issues have more effect on outcomes than tactical issues at the theater-level, and (4) command, control, communications, and intelligence (C^3I) must be the primary focus in a theater-level model [30: 2-4]. The increasing nonlinearity and uncertainty of conflicts dictates the necessity to be able to represent warfare with both uncertainty and variability.

Sidedness refers to the number of collections or alliances of resources working in or through the model toward a common goal [2: 11]. The JWAEP model is a two-sided, asymmetric, reactive model due to its capability of designating specific numbers, types, and characteristics of various weapon systems or tactics for each side. Furthermore, each side has the capability to react to the actions taken by the other side.

2.1.2 JWAEP Qualities

The qualities of a model are defined as the specific entities and processes that the model attempts to represent. The MORS workshop defined the following categories within the quality dimension: domain, span, environment, force composition, scope of conflict, mission area, and level of detail of processes and entities [2: 7]

Domain is the physical or abstract space in which the entities and processes operate [2: 7]. Currently, the JWAEP model operates in both land and air, however, representation of a sea dimension is anticipated.

Span is a subjective description of the scale of the domain [2: 7]. The span of the JWAEP model is to represent any theater of operation in which a terrain data base has been developed. The current span supports a terrain database for Korea.

Environment is the texture or detail of the domain [2: 7]. The environment portrays the conditions in which the operation will occur such as terrain, weather, and NBC. JWAEP uses an arc-node system to portray the environment. As units enter an arc or node, they experience the characteristics and effects of the environment specific to that arc or node until departing.

The current version of JWAEP permits unit movement on two distinct arc-node networks: ground and air. Littoral warfare can be developed by defining carriers as airbases on water nodes and Marine amphibious units as ground units that move over water nodes and arcs connecting to the land until the release of littoral representations

[31: 2]. The networks contain two types of nodes: physical and connector nodes. Physical nodes represent real areas and their associated terrain on the ground or water. Typical representations include cities, key terrain, and other areas of interest particular to a specific scenario. Connector nodes are logical constructs and do not represent actual areas. They are a mechanism through which realistic terrain networks are created. They are used to connect two arcs and have no associated terrain [31:19]. Connector nodes are not visually displayed on the network. The air network utilizes an air grid which overlays the theater of operations. The air grid is analogous to the arcs and nodes of the ground network. The size of the grid can be adjusted to meet scenario requirements [31: 21].

The arcs are used to connect nodes. They are assigned the attributes of the corresponding terrain that lies between the nodes. An arc may contain several connector nodes thus subdividing the arc into several smaller arcs. This subdivision allows the original arc to portray terrain variances. Each arc contains distinct attributes of which the most critical are width and assigned terrain type. Both of these attributes are used to control movement on the arc [31: 20].

The JWAEP model may portray as many terrain types as can be defined by the user. Examples of varying terrain types include flat, rough, mountain, water (naval), water (amphibious), and DMZ. The limiting factor in the creation of terrain types is the ability to obtain data for the resulting effects terrain may have on various other processes such as movement and attrition [31: 18-19]. Also, both man-made and natural obstacles are represented.

The JWAEP model does not currently model weather or its effects except in the air mission planning algorithm. However, the conditions of day and night are modeled in JWAEP.

Force composition is the mix of forces that can be portrayed [2: 7]. The JWAEP model can represent joint and combined forces for both sides. A typical unit size for each side is a maneuver brigade. The asymmetric construction of the JWAEP model enables the user to define as many types of units as desired.

Scope of conflict is the category of weapons available for use by either side [2: 7]. The JWAEP model currently allows the asymmetric use of conventional weapons only. The efforts of this thesis will result in a symmetric capability of nonconventional (chemical) weapons use.

Mission area is the recognized combination of weapons and procedures used to accomplish a specific objective [2: 7]. JWAEP relies on the user defined input of weapons, units, and orders to portray a mission area.

Level of detail of processes and entities is the lowest discrete entity modeled and the lowest level of resolution of the interactive actions which affect these entities [2: 7-8; 17: 14]. The lowest entities modeled in JWAEP are battalion sized maneuver units, flight groups, and major combatant vessels [31: 1]. However, as mentioned earlier, a typical ground unit represented in JWAEP is a maneuver brigade. A maneuver brigade can vary in size and combat power depending on its classification as light or heavy. A typical heavy brigade will consist of approximately 1500 to 2500 soldiers and three to four maneuver battalions.

The JWAEP model contains several processes which enable the model to function properly. Some of these processes currently implemented or under development include attrition, movement, command and control, air planning, and long range fires. The most critical process of the JWAEP model, however, is the command, control, communications, and intelligence (C^3I) process.

The C^3I process is the focal point from which the JWAEP model was developed. This process consists of five functions: planning, detection, fusion, decision, and control [17: 14]. The most critical function is planning; the assignment of sensors at key locations to acquire knowledge about the enemy [31: 1]. The perceptions of enemy units and operations created by the fusion of sensor data provide the basis from which the scheme of maneuver is developed. For example, one side may decide to merge units to strengthen a defensive position if it is perceived that it is along the threat's main avenue of approach. The following section further describes the process in which perceptions are generated.

2.1.3 Existing JWAEP Intelligence Acquisition and Perception

JWAEP uses situation reports of friendly units and spot reports of enemy units to perform intelligence acquisition, fusion, and perception of information.

Spot reports issued by three different types of sensors upon detection of enemy units provide information on existing opposing forces. The types of sensors are combat sensors, network sensors, and scheduled sensors [31: 59-62]. Combat sensors are allocated to both sides and represent the ability of one unit to detect another. Combat sensors issue spot reports on an enemy unit's location, size, strength, and posture.

Network sensors are also allocated to both sides and represent the intelligence collection capability of the owning force along any user-defined subset of arcs and nodes. Network sensors issue spot reports at user-input random intervals reporting all enemy units at the sensor's current node or arc. In contrast, scheduled sensors represent an area reconnaissance or surveillance mission rather than a route. Such sensors may simulate an overhead information gathering system such as a satellite reconnaissance system. Scheduled sensors possess a footprint defined by length and width and issue spot reports on all enemy units on arcs and nodes contained within the footprint.

Sensor fusion is the process which generates an estimate of the enemy situation. This process is accomplished through sensor inputs and Bayesian updating [31: 62]. Inputs from sensor observations on equipment and personnel, either real or "decoy", are fused into probability vectors using a variance weighted Bayesian process. The Bayesian updating compares the equipment and personnel observed versus the equipment and personnel in the most similar Table of Organization & Equipment (TO&E). The resulting probability vector represents the perceived size and type of unit. Therefore, a perception may correspond to an actual enemy unit or a "decoy" enemy unit [32].

2.2 Army Chemical Doctrine

The United States Army Chemical Corps capstone manual, FM 3-100 *Chemical Operations: Principles and Fundamentals*, discusses chemical doctrine concepts in relation to Army operations doctrine. Furthermore, the 3-series Army Field Manuals provide the supporting tactics, techniques, and procedures that incorporate those concepts onto the battlefield. These manuals provide the background in support of the three principles of chemical defense: avoidance, protection, and decontamination [5: iii].

2.2.1 Principle of Avoidance

The most critical element of chemical defense is avoidance [5: 4-1]. Units that avoid detection also avoid being targeted with chemical agents. However, successful deception does not preclude the employment of chemical agents on the battlefield. Therefore, avoidance of chemical agents requires a thorough understanding of these agents, how the environment impacts them, when and how they are used, and detection operations [8: 3-1].

2.2.1.1 Chemical Agents

Chemical warfare agents have been defined as chemical substances, whether gaseous, liquid, or solid, intended for use in military operations to kill, seriously injure, or incapacitate through their physiological effects [10: Glossary-0]. Numerous chemical warfare agents exist and many have been used. Threat forces classify chemical warfare agents according to their effects on the body. However, the United States classifies chemical warfare agents as persistent, non-persistent, and dusty based on the length of agent duration and method of dispersal [8: 3-0]. A dusty agent is one in which a non-persistent or persistent agent is impregnated onto a solid sorbent and dispensed as an aerosol resulting in increased toxicity and persistency [8: 3-1]. Therefore, dusty agents can be considered as a subset of persistent agents.

2.2.1.1.1 Persistent Chemical Agents

The most prominent and well known persistent chemical agents are persistent nerve agent (VX) and blister agent (HD, L, CX, or HL). They are dispersed in the form of solids or liquids and have a persistency ranging from days to weeks. Persistency is defined as duration of time after dispersal that a chemical agent maintains its effectiveness [13: 111]. Although a vapor hazard exists at and near the location of contamination, these agents generally do not form gaseous clouds capable of traveling downwind. Persistent agents produce both immediate and delayed casualties [8: 3-0]. Immediate casualties occur upon inhalation of the vapor or contact with bare skin, usually at the location of dispersal. Delayed casualties occur when the agent is absorbed through the skin, usually as a result of saturation or leakage of an overgarment or desorption from contaminated equipment [9: v]. Delayed casualties may not be affected until hours or days after persistent agent use.

Persistent agents are used for several purposes, all of which rely on their long life expectancy. These uses include impeding the use of terrain, canalizing the opposing force, and contaminating materiel and equipment. For example, an attacker may employ persistent agents on its flanks to guard against a flank attack or against bypassed troops to limit their mobility and effectiveness thus decreasing their ability to engage in combat. Other common uses are to contaminate rear areas such as ports and supply areas [8: 3-0]. Generally, contamination by persistent agents requires decontamination due to the length of persistency.

2.2.1.1.2 Non-persistent Chemical Agents

Non-persistent chemical agents include blood agents (AC or CK), choking agents (CG), and non-persistent nerve agents (G-series) [8: 3-0]. They are usually delivered in the form of a gaseous cloud and typically have a persistency ranging from seconds to days. This gaseous cloud is capable of moving around the battlefield based upon several environmental factors. Non-persistent agents produce immediate casualties and effects due primarily to the inhalation and skin absorption of the gas . Since most non-persistent agents are delivered as toxic gases which disperse or evaporate readily, the requirement for decontamination is diminished significantly [8: 3-0].

Non-persistent chemical agents are used to immobilize, injure, and degrade the effectiveness of an enemy's force. Normally, they are employed along the forward line of troops (FLOT) to create favorable fighting conditions by producing casualties and forcing an enemy into a higher level of protection, thereby degrading their effectiveness [8: 3-0]. For example, an attacker may employ a non-persistent nerve agent slightly upwind of a defensive position at a critical moment of the attack. The wind carries the gaseous cloud over the defensive position producing casualties as well as forcing the unit into a higher level of protection. As the attacker (lower level of protection) advances and occupies the position, the wind disperses the agent from the position. Thus, there is little need for extensive decontamination.

2.2.1.2 Effects of Environmental Conditions on Chemical Agents

The employment and effects of chemical warfare agents are highly dependent upon the environmental conditions of the battlefield. The environmental conditions that have the most impact on chemical agents are: wind direction, wind speed, temperature, air stability, and terrain.

Wind direction determines the direction of travel of gaseous clouds over the battlefield. Typically, a force will employ chemical agents directly on or upwind of the target and only if the wind direction is such that the force will not be threatened by the moving gas cloud.

Wind speed affects the rate at which a gaseous cloud travels as well as persistency for both persistent and non-persistent agents. An inverse relationship exists between wind speed and persistency. As wind speed increases, chemical agents tend to disperse or evaporate more rapidly [9: 6-0]. Generally, low wind speeds are favorable for employment of chemical agents.

Temperature affects the evaporation and dispersion of chemical agents. High temperatures accelerate evaporation and dispersal thus reducing persistency. Conversely, low temperatures tend to increase persistency, especially for liquid agents [9: 6-0]. Also, air temperature determines air stability.

Air stability determines the stability of a gaseous cloud and is dependent upon the temperature gradient. The temperature gradient corresponds to the difference in air temperature at two different altitudes. Air stability is decomposed into three categories: stable, neutral, and unstable. A stable condition exists when the air at the higher altitude is warmer than the air at the lower altitude. The resulting effect is no vertical movement of air. This condition usually exists on clear nights and at sunrise and is highly favorable for the employment of chemical agents [8: 3-10]. A neutral condition exists when there is little or no change in air temperature at different altitudes. This condition usually occurs on overcast days and nights or when wind speeds are greater than 5 knots [8: 3-10]. An unstable condition exists when the air at the higher altitude is significantly cooler than the air at the lower altitude. This condition is the exact opposite of the stable condition and usually occurs on clear days or when wind speeds are less than 5 knots. An unstable condition is the least favorable to employ chemical agents [8: 3-10].

The composition of the terrain affects wind speed and, thus, movement of a gaseous cloud. A chemical cloud will travel over open terrain at the rate of the current wind speed. However, terrain obstacles and vegetation, such as buildings and trees, produce a drag effect on the wind speed resulting in a decreased movement rate of the chemical cloud [7: 1-11, C-15,19].

2.2.1.3 Chemical Planning and Intelligence Procedures

All current and future operations have the potential to occur in a chemical environment. Operational success requires the integration of this condition of warfare into the seven combat functions comprising the Army's Battlefield Operating Systems (BOSs) [12: 2-12]. Chemical planners integrate their plan into the tactical planning process through the use of two processes: the chemical estimate and the Intelligence Preparation of the Battlefield (IPB) [5: D-2-5]. These processes are performed in conjunction with and support each other.

The chemical estimate recommends the most advantageous course of action in relation to the chemical situation and employment of chemical assets based on the mission, enemy, troops, terrain and weather, and time available (METT-T) and the commander's intent. The chemical planner and intelligence officer use the IPB process to establish a perception of the enemy and friendly operations. The IPB process analyzes the terrain, weather, and enemy for a given area and mission. The terrain is analyzed for observation, cover and concealment, obstacles, key terrain, and avenues of approach (OCOKA) and its' impact on the use of chemical weapons [6: D-5]. A similar analysis of current and future weather also determines its' impact on chemical weapon use. Finally, an analysis of the enemy's likely intentions regarding the use of chemical weapons is conducted. Together, these analyses enable the chemical officer to "template" probable locations/targets for persistent agent use and trigger points for employment of non-persistent agents [6: D-5]. In concordance with the chemical estimate and IPB processes, the chemical planner works with the intelligence officer to develop the intelligence collection plan to confirm the estimate. The collection plan may incorporate sensors, unmanned aerial vehicles (UAVs), chemical reconnaissance assets, maneuver unit scouts, and patrols to deny or confirm enemy chemical activities at key times or locations as determined by the chemical estimate/IPB processes. The information obtained from the collection assets provides a perception of the enemy's posture and chemical threat. Based on this perception, the commander may adjust his scheme of maneuver or level of protection.

2.2.1.4 Detection of Chemical Agents

Following Operations Security (OPSEC) measures, the next most important aspect of chemical contamination avoidance is detecting and locating chemical agents [8: 3-1]. The information obtained from chemical warning and reporting in conjunction with chemical reconnaissance enables units to take appropriate protective measures to minimize the effects of chemical agents.

Chemical warning and reporting notifies units of clean and possible contaminated areas. Due to the value of the information, reports of first use of chemical agents are made by the fastest communication means available and widely disseminated [5: 4-4]. Chemical reconnaissance detects and identifies chemical hazards. Chemical reconnaissance assets organic to corps and divisions perform the chemical reconnaissance mission identified by the chemical estimate and IPB processes. Additionally, maneuver units also possess this capability but in a reduced manner due to limited equipment and expertise. Following the detection of chemical agents, the reconnaissance asset marks the contamination boundaries to preclude any further unnecessary contamination of units.

2.2.2 Principle of Protection

The principle of protection is closely related to avoidance. Understanding the foundations of avoidance supports the protection of the force from the effects of chemical agents. Force protection encompasses the actions taken to reduce the vulnerability of a force to chemical attack [10: iii]. These actions include an assessment of vulnerability to chemical attack and the determination of an appropriate level of protection for troops.

2.2.2.1 Chemical Vulnerability Assessment

The chemical planner conducts a chemical vulnerability assessment in support of the chemical estimate. The assessment provides units with an estimate of the probable impact of enemy chemical attacks on their force [10: 3-1]. Based on this impact, recommendations regarding chemical defense postures and chemical unit missions are made to the commander.

2.2.2.2 Mission-Oriented Protective Postures (MOPP)

Mission-Oriented Protective Posture (MOPP) is the flexible use of protective clothing and equipment that balances protection with performance degradation [5: 4-6]. The protective clothing and equipment consists of a protective mask, overgarment, vinyl overboots, and gloves. Table 1 depicts the five levels of MOPP along with an additional protective posture used [10: 2-2-4].

Table 1 MOPP Levels

MOPP Equipment	MOPP Levels					
	MOPP 0	MOPP 1	MOPP 2	MOPP 3	MOPP 4	Mask Only
Mask	Carried	Carried	Carried	Worn	Worn	Worn
Overgarment	Available	Worn	Worn	Worn	Worn	Available
Overboots	Available	Available	Worn	Worn	Worn	Available
Gloves	Available	Carried	Carried	Carried	Worn	Available

As the MOPP level increases, a unit's mission efficiency decreases. This efficiency affects all aspects of the unit mission. The degradation of efficiency is due to the encumbrance of the protective equipment and the accompanying physiological stress, as it relates to temperature. The physiological stress forces a unit to implement work/rest cycles in accordance with the performance task and temperature; as temperature and MOPP level increase, the ratio of work time to rest time decreases [10: 2-6-8]. This degradation is unavoidable, however, it can be reduced through unit acclimation and training. Similarly, various types of equipment, such as tanks, possess overpressure systems which allow personnel to "button up". This action may allow personnel to assume reduced MOPP levels, however, a degradation of effectiveness still occurs. The degradation of effectiveness applies to all aspects of the unit mission. For example, a unit conducting an attack (close combat) in MOPP 4 may have its effectiveness reduced by 26 percent. This means that the unit firing rate, detection, and communication capabilities are reduced by this amount.

The commander determines the appropriate level of MOPP by conducting a MOPP analysis based on a unit's current situation. This analysis attempts to balance the reduced risk of casualties due to chemical agents against the degradation of efficiency as MOPP levels are increased. In order to do so, three situation factors are considered: mission, environment, and soldier factors [10: 2-16].

The unit mission significantly influences the level of MOPP required for adequate protection. An estimate of the level and duration of the work intensity required for mission success is developed. In addition to this estimate of the current mission, an estimate of possible future operations is performed [10: 2-17].

The MOPP analysis also considers the environmental conditions in which the mission will occur. The temperature, humidity, cloud cover, and wind speed determine the unit work/rest cycle. Increasing temperature and humidity while decreasing cloud cover and wind speed results in a lower work to rest cycle ratio [10: 2-20].

Finally, MOPP analysis considers factors relating to the condition of the soldiers. Their levels of physical fitness, training, acclimation, and hydration contribute to an assessment of their overall condition.

Although the theater or corps commander determines the minimum level of MOPP, subordinate commanders maintain the flexibility to adjust the amount of MOPP protection in their particular situations. However, these adjustments may not be lower than the minimum MOPP level specified by the higher headquarters. This flexibility allows subordinate commanders to place all or part of their units in different MOPP levels and still maintain combat effectiveness [10: 2-5].

2.2.3 Principle of Decontamination

The chemical contamination of soldiers, equipment, and terrain results in the degradation of combat power. Decontamination is the process through which this degradation is stopped and combat power is restored. The process of decontamination consumes the same resources required to fight the battle. In order to maximize these resources, decontamination follows four principles [9: 1-2].

1) Decontaminate as soon as possible to restore full combat potential.
2) Decontaminate only what is necessary based on the mission, time, and resources available.
3) Decontaminate as close to the site of contamination as possible to limit its spread.
4) Decontaminate the most important items first and least important items last.

The extent and timing of decontamination efforts depends on the tactical situation, the mission, the extent of contamination, and the decontamination resources available. Decontamination efforts are classified into three levels: immediate, operational, and thorough [9: 1-2-5]. Table 2 describes at each level the techniques involved, optimal times to decontaminate, responsibility for conducting the technique, and the results achieved.

Table 2 Levels of Decontamination

Level	Technique	Optimal Time	Done By	Results
Immediate	Personal Wipedown	Within 15 minutes	Individual or Crew	Stop agent penetration
	Operator Spraydown			
Operational	MOPP Gear Exchange	Within 6 hours	Unit	Limit liquid agent spread
	Vehicle Washdown		Bn Crew	
Thorough	Detailed Troop Decon	When mission allows reconstitution	Unit	Long-term MOPP reduction
	Detailed Equip Decon		Decon Plt	

The amount of time and resources required increases as the level of decontamination increases. Therefore, units normally perform thorough decontamination only after consolidation on an objective or during reconstitution. The removal of contamination to a negligible risk usually requires thorough decontamination. However, if the time for contamination to weather is less than the time required for decontamination, decontamination will not be performed. Although terrain decontamination is possible, it is rarely conducted [9: 5-4].

2.3 Combat Models

Several theater-level combat models offer algorithms and decision logic that model chemical weapons use and their effects. Although each model is conceptually different, they can provide a basis from which to start developing the logic and algorithms required for the modeling of a chemical battlefield in JWAEP. The chemical methodology of the Tactical Warfare Model (TACWAR), Vector-In-Commander Model (VIC), and Joint Theater-Level Simulation (JTLS) are examined.

2.3.1 Tactical Warfare Model (TACWAR)

TACWAR is an automated, deterministic, theater-level combat model used primarily to analyze possible alternative courses of action of operational war plans and force structure mix [24: 2-3]. The model is capable of simulating force-on-force combat, typically at the brigade level or higher, using conventional and chemical weapons. The TACWAR structure consists of a series of submodels executed sequentially on a cyclical basis.

TACWAR uses a Chemical Submodel [25] to assess the impact of chemical warfare and apply the resulting effects to the ground and air assets. Within this submodel, the user specifies a series of chemical packages which contain information about the characteristics of an agent based on weather and the weapon system delivering the agent. Also, the six levels of protection depicted in Table 2-1 are represented and the user determines the minimum and maximum MOPP levels attainable by a unit according to its type and country. Units are assessed some type of degradation ranging from delays to reduced effectiveness associated with wearing chemical protective gear. Upon chemical weapon use, the model determines the extent of contamination and the number of immediate casualties. The removal of chemical contamination from the battlefield occurs through natural weathering of the agent and/or decontamination efforts. Contaminated units are assumed to perform operational decontamination. Therefore, TACWAR only simulates thorough decontamination through the application of time delays. Detection and reconnaissance of chemical contamination as well as chemical units are not represented [25].

2.3.2 Vector-In-Commander Model (VIC)

VIC is a two-sided deterministic simulation of combat at the corps level used to study doctrinal concepts and tactics for combat operations in a variety of scenarios. Typically, combat maneuver units are represented at the battalion level.

Like TACWAR, VIC utilizes a Chemical Module to define the characteristics of chemical weapons use [27]. The Chemical Module contains similar chemical packages to those in TACWAR. In contrast, VIC represents only two levels of protection available to a unit: MOPP levels 1 and 4. Personnel in MOPP level 1 are assessed casualties at the maximum rate defined by the data input while personnel in MOPP level 4 are assessed no casualties. Thus, the unit MOPP status at any given time is equal to the fraction of unit in MOPP level 4; assessment of chemical contamination and casualties as well as unit effectiveness is determined using this MOPP status. VIC also represents discovery loss which is directly related to the detection capabilities of a unit. Units capable of performing chemical reconnaissance are assessed time delays upon encountering undiscovered contamination and subsequently bypass the contamination, if possible. Otherwise, they cross and become further contaminated. Although chemical units are not explicitly portrayed, decontamination units are implicitly represented as decontamination resources assigned to a unit. These resources may perform both operational and thorough decontamination at a user defined rate.

2.3.3 Joint Theater Level Simulation (JTLS)

JTLS is an interactive, multi-sided, deterministic theater-level model designed for analysis, development, and evaluation of operational plans and tactics. The ability to dynamically interact with intelligence, air, logistics, naval, and ground forces enables it to serve as a driver and evaluation tool for wargaming exercises [4: 2-1]. JTLS models the effects of chemical weapons use at a simple level. Although MOPP levels are not represented, units may suffer both immediate and delayed casualties upon exposure to chemical contamination as well as degradation of movement. However, degradation of unit effectiveness, reconnaissance, and decontamination is not portrayed [4: 7-3].

2.3.4 Summary of Combat Models

Table 3 compares the representation of chemical warfare within the TACWAR, VIC, and JTLS combat models.

Table 3 Comparison of Existing Combat Models

Area of Focus \ Model	TACWAR	VIC	JTLS
Levels of MOPP	6 Levels (MOPP Levels 0-4 and mask only)	2 Levels (MOPP Levels 0 and 4)	None
Attrition	Immediate	Immediate	Immediate and Delayed
Degradation	Effectiveness and Movement	Effectiveness and Movement	Movement
Decontamination	Thorough	Operational and Thorough	None
Reconnaissance and Detection	None	Yes, but no capability to detect prior to encounter	None
Treatment of Randomness	Deterministic	Deterministic	Deterministic
Sidedness	Two-sided	Two-sided	Multi-sided

2.4 Summary of Literature

The existing JWAEP composition, current U.S. Army chemical doctrine, and information and concepts drawn from other combat models can be used to model chemical weapons use and their resulting effects in JWAEP. Each of the combat models represent chemical weapons use in a distinct manner, however, none capture neither the uncertainty nor the full effects of unit encounters with chemical agents. The TACWAR and VIC models do provide a solid foundation for representing the parameters required to model chemical weapons use. Specifically, these parameters include attributes associated with weather conditions.

III. METHODOLOGY

3.1 Modeling Chemical Units

As discussed in Chapter I, the role of chemical units on the battlefield is to enhance the combat power of a maneuver force. Their ability to act as combat multipliers is accomplished through the use of their critical assets. These assets primarily consist of decontamination apparatuses and reconnaissance vehicles which possess virtually no "force killing" capabilities. Furthermore, chemical units rarely operate larger than company sized and frequently at the platoon level. Therefore, due to the relatively small unit size in relation to unit size normally represented in a low resolution model, chemical units are not explicitly portrayed in the modeling effort. Rather, their assets are implicitly represented by associating an appropriate number of chemical "resources" to a maneuver force, as dictated by the maneuver force task organization. Appendix A lists the type and number of assets normally associated with U.S. maneuver forces and Appendix B provides a description of the various types of chemical equipment. Further discussion of this representation is provided in Sections 3.7 and 3.10.1.

3.2 Methodology Assumptions

The methodology section of this thesis uses the following assumptions in developing the logic and algorithms used to portray chemical weapons use and effects in JWAEP.

1) A weather module (to be developed in future JWAEP versions) will provide the required weather parameters for the chemical module [29].

2) Unit personnel and equipment are uniformly distributed throughout a unit formation.

3) Units are well trained in chemical defense measures and properly employ chemical equipment.

4) All units can possess the capability to conduct chemical surveys [8: 5-1].

5) A chemical contamination area or cloud contains one concentration within its borders.

6) No attempt is made to track which part of a unit is affected by chemical agents. Therefore, the effects of chemical weapons use are determined assuming mathematical independence.

7) Immediate decontamination always occurs and is reflected in the agent weathering time [9: 1-2].

8) The spread of contamination on the battlefield by units is not represented due to removal of gross contamination by decontamination efforts [9: 1-2].

9) Long term effects (delayed) casualties will not be modeled.

3.3 Methodology Overview

The methodology for modeling chemical weapons use and their effects on the battlefield within JWAEP incorporates the aforementioned assumptions and is presented in a sequential manner based upon their logical order of development and appearance in combat:

1) Identifying required parameters currently nonexistent within JWAEP.

2) Developing the structure for representing chemical agents.

3) Defining the characteristics associated with chemical agent employment.

4) Obtaining intelligence on chemical agent employment and its detection.

5) Calculating the associated time and attrition effects of chemical weapons use.

3.4 Parameter Requirements

The modeling of chemical weapons and their effects requires information to be available from within the model. Much of this information, in the form of parameters, currently exists in JWAEP and requires no further modeling. However, the absence of some parameters necessitates developing the logic and structure required for their inclusion into JWAEP and use in representing chemical weapons on the battlefield.

3.4.1 Weather

As discussed in Section 2.2.1.2, several environmental conditions have a direct influence on the size and persistency of chemical contamination. These conditions include wind direction and speed, temperature, and air stability. Typically, they are the minimum requirements for the weather of a model. Weather is defined as the state of the atmosphere, mainly with respect to its effects upon life and human activities [7: Glossary-9]. Therefore, an accurate portrayal of chemical agents and their behavior must account for the effects of weather. However, weather currently does not exist within JWAEP. Hence, the subsequent paragraphs outline the basic requirements and logic required to represent the effects of environmental conditions on chemical contamination.

The TACWAR and VIC models utilize a similar method of representing the effects of weather on chemical contamination and provide the basis for developing weather in JWAEP. Both models utilize global weather, which consists of the environmental conditions stated above, and local terrain influence to determine the characteristics of chemical contamination. This combination of global weather and local terrain influence determines the local weather [25: 3-11, 27: 14-3].

Wind direction is the compass direction from which the wind blows [7: C-4]. Within JWAEP, unit headings are determined from the X axis (0 or 360 degrees is east). Similarly, wind direction should also be determined from the X axis. For example, a unit moving on a heading of 90 degrees is traveling north. Conversely, a wind direction of 90 degrees signifies a wind blowing from north to south.

Temperatures are defined as classes which represent the ranges of degrees Fahrenheit for each class [25: 3-13, 27: 14-3]. The user determines the number and range of classes and should cover all possible temperatures that the model will be using. A prototype of definition of temperature classes and ranges is provided in Table 4.

Table 4 Prototype of Temperature Classes and Range (Degrees Fahrenheit)

Class:	1	2	3	4	5	6
Range:	-50-40	41-60	61-75	75-100	100-120	121-160

The two extreme temperatures are set at values that are unlikely in order to place bounds on their respective classes.

Classes are also used to define the combined entity of wind speed and air stability [25: 3-12, 27: 14-3]. This combination reduces the number of dimensions required in tables that define the characteristics of the chemical contamination. The user determines the number and range of classes and should cover all possible wind speed and air stability categories that the model may encounter. The wind speed entry corresponds to the maximum wind speed (km/hr) that a class contains. Thus, wind speed for a specific class ranges from the previous class wind speed to its own wind speed. The air stability categories are separated into three distinct categories of STABLE, NEUTRAL, or UNSTABLE or may be combined into one category (ALL) signifying that they are irrelevant at a particular wind speed range. If distinct air stability categories are used, then all categories must be represented for that specific wind speed range. A prototype of definition of wind speed/air stability classes is provided in Table 5.

Table 5 Prototype of Wind Speed / Air Stability Classes

	Air Stability			
Wind Speed	STABLE	NEUTRAL	UNSTABLE	ALL
0 - 4				1
5 - 10				2
11 - 25	3	4	5	

The limiting factor in defining the appropriate temperature and wind speed/air stability classes to be used for a specific scenario is the availability of accurate data representing the characteristics of chemical agents. This data as well as degradation factors discussed in later sections should be provided by the U.S. Army Chemical School.

The local weather is a combination of the global weather and local terrain influence. The local terrain influence is a numerical representation of the amount of drag effect that obstacles and vegetation have on the wind speed for a particular type of terrain. This value is called the wind speed reduction factor and is multiplied times the global wind speed to determine the local wind speed used in the movement of chemical clouds. The user determines the wind speed reduction factor for each type of terrain. Within JWAEP, terrain is currently categorized by type without consideration of the amount or type of vegetation [31: 19]. However, since JWAEP's current span is Korea, some inferences may be made about the amount of vegetation a type of terrain possesses. Flat terrain contains little vegetation due to the agricultural emphasis in the countryside. Rough terrain contains a moderate amount of vegetation and natural obstacles. Mountainous terrain contains a considerable amount of vegetation while urban terrain contains a significant amount of manmade obstacles. Using these inferences, wind speed reduction factors for each type of terrain within JWAEP are defined in Table 6.

Table 6 Wind Speed Reduction Factor for Terrain Type

Terrain Type:	Flat	Rough	Mountain	Urban	DMZ	Water
WSRF:	0.9	.8	.6	.6	.9	1.0

3.4.2 Unit Protective Postures

A unit's protective posture is a primary factor in determining the number of casualties due to exposure to chemical agents. The encumbrance of protective clothing in conjunction with work/rest cycles based on temperature also has a direct effect on the effectiveness of a unit in performing its tasks. Therefore, an accurate representation of protective postures within JWAEP enables units to capture both of these effects.

Unit protective postures are represented by three distinct levels: no protection, partial protection, and full protection. An increase in protective posture provides an increase in protection. However, associated with this increase in protection is a decrease in unit effectiveness due to encumbrance and temperature based work/rest cycles. The user determines the representation of the levels of protection for each side according to the protective equipment available to personnel. These representations may not be equivalent, however, the differences are accounted for in the capabilities of the protective levels and their degradation effects for each side. For example, the U.S. military uses five levels of MOPP and a mask-only posture, described in Table 1, to determine an appropriate level of protection for personnel against chemical weapons use. Although differences in protection and effectiveness exist at each level of MOPP, the differences are rather negligible between MOPP levels 1 and 2 as well as MOPP levels 3 and 4 [22: 4-3]. Also, a mask-only posture may only be worn by personnel sheltered from non-persistent agents. Commanders will not use this posture when the presence of blister or persistent nerve agents is known [10: 2-4]. Therefore, the protective postures for U.S. forces can be classified into one of three different levels of MOPP: MOPP 0, MOPP 1, and MOPP 4. These MOPP levels correspond to the unit's protective levels as no protection, partial protection, and full protection, respectively. Conversely, suppose a side has only protective masks available for personnel. Full protection would represent personnel in these protective masks while partial protection would be equivalent to no protection. In this case, the casualty effects of persistent chemical agents on personnel in full protection would be drastically different than U.S. forces in the same protective level.

The user realistically portrays a commander's MOPP directive by determining the initial protective posture applicable to a side. The initial protective posture represents the minimum level of protection a unit conducts its operations in regardless of the presence of chemical agents. Table 7 depicts the rules associated with levels of protection.

Table 7 Unit Protective Level Rules

Minimum Protection Level	Maximum Protective Level
No Protection (NProt)	Full Protection (FProt)
Partial Protection (PProt)	Full Protection (FProt)
Full Protection (FProt)	Full Protection (FProt)

Units may assume both the minimum and maximum levels of protection at any one time. Thus, units with a protective level of no protection will assume full protection in response to a chemical hazard. Upon removal of the hazard, the unit level of protection is reduced to no protection. In this case, the unit may not assume partial protection unless the user redefines its minimum level of protection.

The following example illustrates the process of determining a side's initial protective posture. Typically, U.S forces operating at a level of no protection signifies the absence of potential enemy chemical weapons use in theater, thereby negating any further requirements for an increased level of protection. However, if the threat of enemy chemical weapons use exists, the commander's chemical vulnerability assessment will normally specify a minimum MOPP level of 1 or partial protection. Since JWAEP's current span is Korea, this assessment will also specify the minimum level of protection as partial protection. Using this process, initial protective postures may also be defined for threat forces as well.

A unit encountering chemical agents must adjust its level of protection until the hazard no longer remains. Allowing a unit the flexibility of varying its level of protection required for a particular situation enables it to maintain its combat effectiveness as well as realistically representing a subordinate commander's decision to increase the level of protection to any part of his unit. This consideration is especially important considering the large brigade size units typically represented within JWAEP. For example, if a brigade size unit in partial protection receives 5 percent persistent agent contamination which has no downwind vapor hazard, only 5 percent of the unit will assume a level of full protection while the remainder of the unit maintains its current protective level. Upon the removal of the chemical hazard, the level of protection for the 5 percent is reduced to partial protection. Thus, unit protective levels do not have an all or nothing effect on a unit.

3.4.3 Degradation Due To Levels of Protection

As discussed in the previous section, unit protective levels have a significant impact on the conduct of operations. It provides protection from chemical agents at the cost of reducing a unit's effectiveness and movement rate.

The number of casualties resulting from exposure to chemical agents is directly related to a unit's protective level. The higher the level of protection, the lower the number of casualties. A chemical package, discussed in the next section, contains a lethality value which represents the fraction of personnel killed when exposed to the chemical package, assuming personnel are in no protection. Therefore, an increase in protective levels results in a reduction in lethality. Table 8 provides an example of lethality reduction factors for each side, level of protection, and type of chemical agent.

Table 8 Example of Lethality Reduction Factors

	Unit Protective Levels			
	Side 1		Side 2	
Agent Type	PProt	FProt	PProt	FProt
Non-Persistent	.85	.02	.9	.04
Persistent	.7	.02	.8	.04

These values are dependent upon each side and the user's representation of their levels of protection. The lethality reduction factors represent the fraction of lethality that is used in determining casualties and, therefore, is multiplied times the chemical package lethality to obtain the overall lethality factor. Table 8 assumes that personnel in no protection receive the maximum number of casualties possible as defined by the chemical package lethality while personnel in full protection receive significantly reduced casualties. Also, the difference in lethality reduction factors between agent types for protective levels is attributed to the protection provided by this level and the hazards each agent presents. Non-persistent agents are primarily a vapor hazard while persistent agents present more of a hazard to exposed skin. Thus, assuming a side has unit protective levels similar to U.S. forces, partial protection typically provides more protection against persistent agents than non-persistent agents [10: 2-3-4].

The degradation of unit effectiveness for a specific activity and unit due to protective levels is a combination of the encumbrance of the protective clothing and the work/rest cycle associated with temperature. Although the TACWAR model has no regard to unit type, it does provide a basis for implementing degradation into JWAEP [25: 5-9-15]. Temperature classes are separated into distinct temperature ranges based on their effects on degradation. For example, using Table 4, the six temperature classes could be classified into two temperature ranges: temperature range 1 consists of classes 1 through 3 while temperature range 2 consists of classes 4 through 6. Within JWAEP, units exist as one of five categories: armor/mech, motorized, infantry, aviation, and artillery. The first four categories are classified as maneuver units while artillery is a support unit. Both types of units have a distinct set of orders or activities which they may conduct [31: 42-44]. Table 9 depicts the various types of orders conducted by maneuver and support units that may incur a degradation of effectiveness.

Table 9 Unit Orders

Classification of Unit	Order (Activity)
Maneuver	Attack
	Defend
	Delay
	Movement to Contact
	Tactical Assembly Area
	Tactical Road March
	Administrative Road March
Support	General Support
	Direct Support
	Tactical Assembly Area
	Tactical Road March
	Administrative Road March

Although unopposed movement is not a specific order, it is an activity. Therefore, the tactical and administrative road marches as well as unopposed movement for any of the other activities can be categorized into one activity for degradation purposes: unopposed movement. By doing so, the degradation of the unopposed movement rate for a unit in a specific level of protection is the same regardless of the activity being performed. However, all other tasks such as communication and target acquisition are degraded to the value specified for the activity in general. This degradation is used in the adjudication of close combat which is not discussed in this thesis. The amount of degradation of effectiveness for a specific activity may vary depending upon the type of unit. For example, a light infantry unit in full protection will experience a greater degradation of effectiveness than an armor unit under the same conditions. This is attributed to the overpressure capability of armored vehicles, thereby affording personnel to assume a lower level of MOPP while still being protected. Therefore, each activity for a unit category must have an associated effectiveness degradation factor for each increased level of protection and temperature range. Although degradation will most likely increase as the length of time a unit remains in a heightened protective level increases, the degradation factor assumes that the unit follows the work/rest cycles over time and thereby avoids any further degradation. Thus, the degradation factors represent the level of effectiveness of personnel in an increased level of protection in comparison to personnel in no protection and take into account both the encumbrance of the protective clothing or "buttoning up" and the work/rest cycles associated with the temperature ranges.

The instantaneous overall unit effectiveness ($Eff_{Overall}$) for a specific activity is computed according to the following equation:

$$Eff_{Overall} = [(NProt_{Overall}) + (PProt_{Overall})*(Eff_{PProt}) + (FProt_{Overall})*(Eff_{FProt})] \quad (1)$$

where

$NProt_{Overall}$ = the overall fraction of unit in no protection
$PProt_{Overall}$ = the overall fraction of unit in partial protection
$FProt_{Overall}$ = the overall fraction of unit in full protection
Eff_{PProt} = the effectiveness degradation for personnel in partial protection while performing a specific activity
Eff_{FProt} = the effectiveness degradation for personnel in full protection while performing a specific activity

The effectiveness degradation factors for all activities while in no protection will always equal one. Thus, the unit effectiveness is determined using a weighted average based on the fraction of unit in each of the three levels of protection.

An example of determining the overall unit effectiveness for a specific activity is provided to illustrate the application of Equation (1). An armor unit moving unopposed is conducting an attack in 60 degree Fahrenheit weather (temperature range 1) with 90 percent of its personnel in partial protection and 10 percent in full protection. The unopposed rate of movement in no protection is 20 km/hr and the associated effectiveness degradation factors for temperature range 1 are:

Unopposed Movement in Partial Protection: .95
Unopposed Movement in Full Protection: .8
Attack in Partial Protection: .9
Attack in Full Protection: .72

Using Equation (1):

Unopposed Movement:

$$Eff_{Overall} = [(NProt_{Overall}) + (PProt_{Overall})*(Eff_{PProt}) + (FProt_{Overall})*(Eff_{FProt})]$$
$$Eff_{Overall} = [(0) + (.9) * (.95) + (.1) * (.8)]$$
$$Eff_{Overall} = .935$$

Attack:

$$Eff_{Overall} = [(NProt_{Overall}) + (PProt_{Overall})*(Eff_{PProt}) + (FProt_{Overall})*(Eff_{FProt})]$$
$$Eff_{Overall} = [(0) + (.9) * (.9) + (.1) * (.72)]$$
$$Eff_{Overall} = .882$$

Thus, the overall unit effectiveness while moving unopposed is .935 and is multiplied times the unopposed movement rate in no protection (20 km/hr) to determine the effective movement rate (18.7 km/hr). Similarly, the unit effectiveness for conducting an attack, should the unit become engaged, is .882 or 88.2 percent of what it would be if the unit were in no protection at its current state.

3.5 Chemical Package Structures

The representation of chemical agents on the battlefield utilizes methodologies found in both JWAEP and other combat models. The TACWAR and VIC models utilize the concept of chemical packages to represent the effects of chemical weapon use [25: 3-1, 27: 14-7]. The chemical packages are a collection of parameters that describe the chemical agent characteristics and method of delivery for a specific number of munitions and scenario. Within JWAEP, obstacles are modeled using prototypes similar to that of a unit [28: 33]. Obstacles are defined as any physical characteristic of the terrain which impedes the mobility of a force [28: 13]. Chemical agents also have this effect and, therefore, can be regarded as a type of obstacle. Hence, chemical packages within JWAEP are modeled as obstacles.

3.5.1 Chemical Package Prototypes

A chemical package exists as a user defined prototype. The type and number of chemical package prototypes used in a particular scenario is also controlled by the user, however, an accurate representation of enemy employment capabilities is required. Typically, enemy capabilities include both persistent and non-persistent chemical agents delivered by artillery, missiles, and bombs. Each prototype contains several fields which describe the characteristics of chemical agent represented by the chemical package. These characteristics are provided by the chemical packages defined in TACWAR [26]. Table 9 on the following page illustrates an example of a chemical package prototype for a non-persistent agent (GB) delivered by artillery.

In the example in Table 10, the chemical package type is defined with the four-digit number 1900. The side, 2, depicts enemy. The type defines the specific chemical agent and its classification as non-persistent or persistent. The lethality represents the fraction of personnel killed when exposed to the chemical package, assuming personnel are in no protection. The delivery system identifies the weapon from the *equipment.dat* file used for employment of the chemical package. The rounds required are the number of rounds

Table 10 Chemical Package Type Definition

```
1900 "GB - Artillery"
SIDE....TYPE....LETHALITY....DELIVERY.SYSTEM....ROUNDS.REQUIRED
 2    NP-GB      0.9              2530                 6

RADIUS(KM).AND.DOWNWIND.STRETCH.DISTANCE(KM).AND.PERSISTENCY
  (MIN).BY.WIND.AIR.STAB.CAT.BY.TEMPERATURE.CAT

                                TEMPERATURE.CATEGORY
WIND.AIR.STAB.CAT.......1...............2...............3...............4...............5...............6
           1       .15 1.6 125  .15 1.8 50  .15 1.9 20  .15 2.0 10  .15 2.1 5  .15 2.2 1
           2       .08  .6 120  .08  .6 45  .08  .6 21  .08  .7 10  .08  .7 5  .08  .7 1
           3       .07  .5 115  .07  .5 45  .07  .5 20  .07  .5 10  .07  .5 5  .07  .5 1

END.RADIUS(KM).AND.DOWNWIND.STRETCH.DISTANCE(KM).AND.
  PERSISTENCY(MIN).BY.WIND.AIR.STAB.CAT.BY.TEMPERATURE.CAT
```

that must be fired by the delivery system to employ the chemical package. Finally, the table defines the radius, downwind stretch distance, and persistency associated with the chemical package according to the user defined temperature and wind speed/air stability categories. Since persistent agents present a negligible downwind vapor hazard, the values entered for their downwind stretch distance equal 0. Otherwise, the structure of the prototypes is the same for all chemical packages. Appendix C, Chemical Package

Prototypes, depicts six possible chemical packages which describe several methods of delivery and agent characteristics for specific classes of weather.

3.5.2 Chemical Package Instances

The current JWAEP instance architecture enables the user to quickly define maneuver forces and obstacles over the entire theater for a specific scenario. The behavior of these instances is governed by sets of orders specifying actions to occur at designated times such as initialize and attack [31: 25]. Instances of chemical packages follow the existing JWAEP instance architecture for obstacles with some modifications.

Each instance of chemical packages has three parameters and a set of orders that define it. The parameters include a package number, center of mass location and the quantity of packages employed. Chemical agents are delivered on the battlefield by missiles, aircraft, and indirect fire. Therefore, it is logical to utilize the targeting and firing methodologies for each of these delivery systems to initialize chemical package instances in the scenario. Hence, an additional order must be added to the order stream: EMPLOY. This order specifies the simulation time at which the employment of chemical weapons may commence. Table 11 depicts a possible chemical package instance.

Table 11 Chemical Package Instance

```
PACKAGE.ID
    1900        "GB - Artillery"
  CENTER.MASS.......QUANTITY
    UT46927435            3
ORDERS
  DELTA.TIME.........TYPE
       0.0            EMPLOY
END.ORDERS
```

The "center of mass location" and "quantity of packages employed" parameters specified in Table 11 reflect the capability of scripting chemical weapons use. However, the user may utilize the delivery weapon targeting procedures to determine these parameters. In either case, the creation of a chemical package instance is dependent on the availability of the delivery weapon and the required number of rounds as well as the center of mass location being within the delivery weapon's range. The integration of chemical weapons employment into the existing targeting and firing methodologies and procedures is not addressed in this thesis and is left for future work.

3.6 Chemical Package Attributes

Defined within the chemical package prototypes are various attributes that the instance will inherit. These attributes include lethality, radius, downwind stretch distance, and persistency. Upon determination that a chemical package instance should be created, the instance attributes are determined according to the current weather conditions. These attributes are sensitive to any changes in the weather conditions. Thus, chemical packages must maintain the flexibility to adapt to the environmental conditions.

3.6.1 Chemical Package Formation

As mentioned in the previous section, the size of the chemical package is dependent upon the current weather conditions. Initially, both persistent and non-persistent chemical package hazards are represented as a circle with a radius defined by the weather conditions. The center of mass location of the circle is the user specified location found in the chemical package instance or the aim point determined by the delivery weapon targeting mechanism. Since persistent agents possess a negligible downwind vapor hazard, their dispersal remains a stationary circle. However, the downwind hazard associated with non-persistent agents requires a more extensive representation. The downwind end of the circle elongates at the rate of the local wind speed (the global wind speed with local terrain influence) until the downwind stretch distance is reached, resulting in an oval-shaped package. At this time, the chemical package "breaks free" and travels across the terrain at the rate of the local wind speed. Both types of chemical packages remain on the battlefield for their defined persistency. Upon expiration of persistency, the instances are removed from the simulation. Figure 2 depicts the formation of a chemical package.

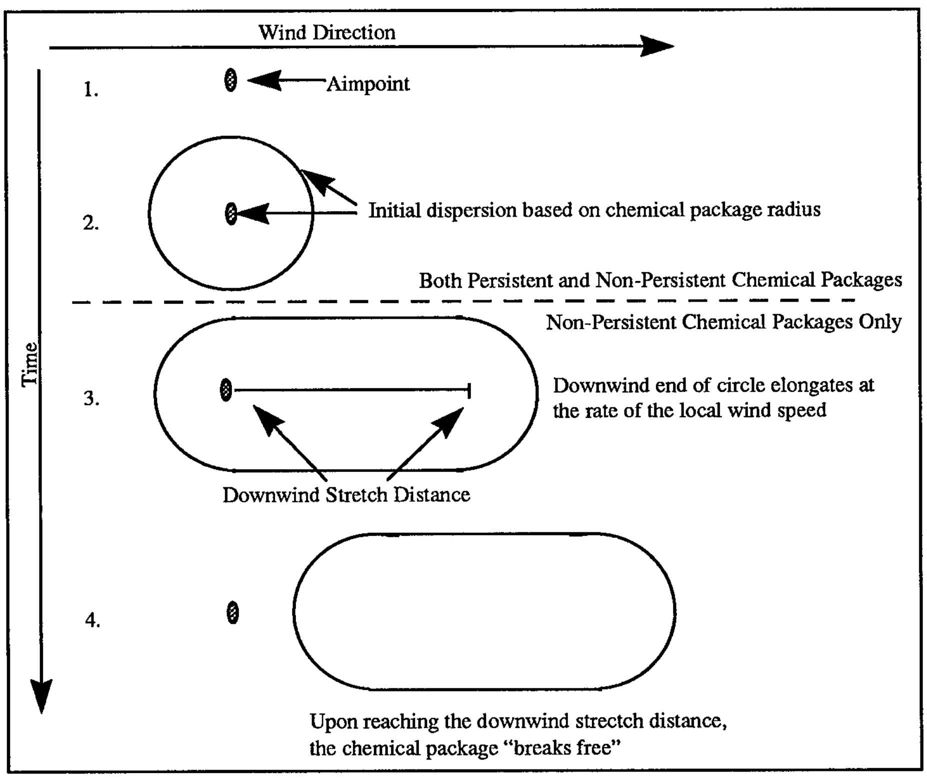


Figure 2 Chemical Package Formation

As stated earlier, steps 1 and 2 are identical for both types of chemical packages. Steps 3 and 4 reflect the growth associated with a non-persistent package only. Although chemical agents rarely disperse in a "perfect" circle, this representation simplifies the data support requirements while capturing the general effects of dispersion. Also, similar methods of dispersion are found in both the TACWAR and VIC models [25: 3-2-7, 27: 14-24-26].

If chemical weapons use is not scripted, the targeting process associated with the delivery weapon determines the number of chemical packages to be employed. If one package is employed, the formation of the chemical package uses the appropriate radius found in the prototype. Otherwise, the radius, R_C, is determined using Equation (2) provided by the TACWAR model [25: 5-26].

$$R_C = [(R_C \text{ from Chemical Package Prototype})^2 * (\text{Number of Packages})]^{.5} \quad (2)$$

For example, an artillery targeting process has determined that it requires four chemical packages. The current temperature and wind speed/air stability classes are 3 and 1, respectively. Using the example chemical package prototype in Table 10, a single chemical package radius is 0.15 km.

From Equation (2):

$$R_C = [(R_C \text{ from Chemical Package Prototype})^2 * (\text{Number of Packages})]^{.5}$$
$$R_C = [(0.15\text{km})^2 * (4)]^{.5}$$
$$R_C = 0.3 \text{ km}$$

Thus, the radius of the chemical package instance is 0.3 km. The remaining attributes remain unchanged regardless of the number of packages employed.

3.6.2 Effects of Weather Changes

The attributes used in the formation of a chemical package are determined according to the current weather conditions. To ease computational requirements, the size of the chemical package remains unchanged regardless of any further variations in the weather conditions. The typically small persistency associated with non-persistent agents and the inability of persistent agents to move once employed supports this methodology. However, if variations in the weather conditions occur, the resulting effects are represented through the persistency of the chemical packages and the direction and rate at which a non-persistent chemical package travels.

The persistency of a chemical package is determined from the chemical package prototype upon employment. If variations in weather conditions result in the use of different temperature or wind speed/air stability categories after employment, a new persistency must be determined. The required parameters include the remaining persistency under the current weather conditions, P_t, and the raw persistencies for the current and new weather conditions specified in the chemical package prototype, respectively CP and NP. Equation (3) determines the new remaining persistency, P_{t+1}, associated with a change in the temperature or wind speed/air stability categories.

$$P_{t+1} = (P_t / CP) * NP \tag{3}$$

The following example illustrates the use of Equation (3). The raw persistency specified for a chemical package at the time of employment is 600 minutes. A change in the weather conditions 400 minutes later results in a new temperature category. The raw persistency associated with the new conditions is 300 minutes. The given information:

$CP = 600$ minutes
$P_t = 600$ minutes - 400 minutes = 200 minutes
$NP = 300$ minutes

Using Equation (3) to determine the new persistency (P_{t+1}),

$$P_{t+1} = (P_t / CP) * NP$$
$$P_{t+1} = (200 \text{ minutes} / 600 \text{ minutes}) * 300 \text{ minutes}$$
$$P_{t+1} = 100 \text{ minutes}$$

The new persistency associated with the chemical package is 100 minutes. This process is repeated for further changes in weather conditions until the persistency has expired. It should be noted that persistency may increase under the appropriate conditions.

The direction and rate a non-persistent chemical package travels is dependent upon the wind direction and speed. Thus, any change in these weather attributes affects the movement of the chemical package. The chemical package always travels in the direction of wind. Therefore, the downwind end of the chemical package is considered the front of the package and oriented in the direction of the wind. Hence, a shift in the direction of the wind results in a shift in the orientation of the chemical package. The chemical package pivots until the cloud is aligned with the direction of the wind. Likewise, an increase or decrease in the wind speed will have a proportional effect on the rate of movement over the same terrain type.

3.7 Chemical Package Intelligence Acquisition and Perception

As discussed in Chapter II, one of the most important aspects of chemical contamination avoidance is detecting and locating chemical agents. Obtaining information concerning the location, type, and size of chemical contamination is critical in maintaining the mobility and effectiveness of a maneuver force. Commanders acquire this information through a variety of assets in support of the chemical estimate and intelligence preparation of the battlefield [6: E-0-3]. These assets span from individual soldiers to remote sensors. Likewise, JWAEP utilizes human reporting and sensors to obtain intelligence on enemy units. Therefore, by representing a chemical package as a "unit" within JWAEP, chemical package intelligence acquisition procedures may follow the same architectural framework that exists for enemy unit acquisition procedures. In so doing, the existing sensors and sensor fusion process used for enemy units can be used for chemical packages, with minor modifications to the sensor inputs. Recall from Section 2.1.3, the current fusion and Bayesian updating process is based on these sensor inputs. Therefore, chemical package intelligence acquisition will be updated using the Bayesian process and the following algorithm:

1. Sensors provide input reports on chemical packages to include the following fields:
    a. *Type of chemical package: persistent or non-persistent and agent.
    b. *Radius of chemical package.
    c. Downwind stretch distance of chemical package.
    d. Lethality.
    e. Remaining persistency.
    f. *Location of chemical package (center of mass).
2. All sensor inputs on chemical packages are received and fused.
3. Fused sensor inputs for fields of chemical packages are compared to fields of the most similar chemical package prototypes.
4. A probability vector is created via the Bayesian process for all chemical packages. The vectors depict the probability or perception that a chemical package exists, its size and location, and the type of chemical package.

In contrast to the enemy unit acquisition process which uses all three types of JWAEP sensors, chemical package detection and intelligence acquisition will use only combat and scheduled sensors. Combat sensors will be used to represent the ability of a unit to report its observations concerning chemical agent employment. These reports may be initiated by such events as artillery impacts, observing enemy units in a chemical posture, and sensing by detection equipment. Combat sensors representing personnel will report only the fields denoted by (*) in the above algorithm, and will typically be subject to significant error unless supported with reports by detection sensors. Scheduled sensors implicitly represent the intelligence gathering capabilities of valuable chemical reconnaissance vehicles and sensors and, hence, must be positioned according to the chemical intelligence preparation of the battlefield and the commander's intent. The locating of these limited sensor assets is critical in providing confirmation of suspected enemy chemical weapon use and thereby maintaining maneuver force mobility and combat power. Network sensors are not used since there exists no current chemical contamination detection equipment with capabilities similar to the types of assets modeled by these sensor models. Appendix B provides a description of the various types of equipment used to detect chemical agents. Thus, a perception of the use of chemical weapons use, real or "decoy", can be generated using JWAEP's current sensor and fusion model with only minor modifications to the sensor field specifications.

The following example illustrates the generation of chemical package perceptions using the fusion and Bayesian updating process. There are 2 chemical package prototypes defined for this example. Thus, the possibilities of chemical package existence are:

(0, 0) - Nothing there
(1, 0) - Chemical package 1 (Persistent VX)
(0, 1) - Chemical package 2 (Non-Persistent G)

The prior distribution at time 0 for each of these possibilities are:

(0, 0) = 0.9
(1, 0) = 0.05
(0, 1) = 0.05

This prior distribution reflects a large probability that nothing exists and an equally likely, although small, probability that either one of the chemical packages exists.

A unit observes artillery impacts approximately 3 km from its current position (combat sensors). This impact area has been templated during the IPB process for a possible chemical attack. Therefore, the commander has pre-positioned NBC reconnaissance assets (M21 remote sensor) near the location to observe the area of interest (scheduled sensors). The unit sends the following report at time 1 based on the artillery impact and the templated area:

Type of Chemical Package: Persistent VX
Location: grid location a
Estimated Radius: 800 meters

This report is subject to significant error since it has not been verified as yet by detection equipment. However, a perception is generated by fusing the report and comparing the fields reported to the fields of the chemical package prototypes to determine the chemical package that most closely resembles the fields reported. Remember, the possibility exists that the report may be false (the degree depends upon the sensor) and nothing exists. At time 2, the M21 sensor submits a report with the following information:

Type of Chemical Package: Non-Persistent G
Location: grid location b
Estimated Radius: 600 meters
DSD: 1800 meters
Lethality: 0.7
P_t: 15 minutes

The report from the M21 is much more reliable and therefore has a higher probability of correct classification of package prototype fields. This report is fused with the time 1 report to generate perceptions at time 2. Thus, the perception generated would generally reflect a higher perception of non-persistent existence.

The fusion and Bayesian updating process is described in detail within a working paper developed at the Naval Postgraduate School [16]. However, the perceptions generated by the sensor reports for the example described above as well as the conditional posterior moments are provided in Table 12. As expected, the perception at time 1 reflects a great deal of uncertainty as to the existence of a chemical package. At time 2, the report from the sensor is much more accurate and reliable thereby resulting in approximately a probability of 1.0 of the non-persistent chemical package existence.

3.8. Unit Tactics and Orders Upon Perceiving or Encountering Contamination

Perhaps the most critical combat function of the Army Battlefield Operating Systems (BOS) is achieving and maintaining mobility. Mobility operations preserve the freedom of maneuver of friendly forces and reduce the risk associated with unit missions [12: 2-14, 5: 1-5]. Although not specifically defined as such, a unit may conduct several actions to maintain its freedom of maneuver upon perceiving or confirming that chemical weapons have been employed. These actions include chemical reconnaissance, chemical surveying, bypassing, and crossing.

Chemical reconnaissance is conducted to confirm or deny the presence of persistent chemical packages since they are the major chemical threat on the battlefield [11: 3-0].

Table 12 Results of Perception Updating and Fusion Example

		Chemical Packages Defined (2)																		
	#1 - P VX		#2 - NP G			Sensor Error:									To Determine Normailzation Contant (C)					
Attribute	Mean	Std Dev	Mean	Std Dev		Personnel	M21		Initial Priors at Time 0:						(0, 0)	(1, 0)	(0, 1)	C		
Radius	900	300	500	200		400	100		Nothing = Large (.9)					Time 1	0.0001215	4.191E-05	3.635E-05	5006.3772		
DSD	0	0.5	1600	1000			300		Either Type of Package = Equally Likely (.05)											
Lethality	0.8	0.2	0.6	0.2			0.05							Time 2	3.634E-24	2.035E-21	3.448E-09	290035568		
Pt	2000	500	30	20			15													
												Conditional Posterior Moments Given Chemical Package Type								
		Estimated Value of Reported Attributes				Posterior Distribution (Package Type)				No Chemical Package				Chemical Package #1				Chemical Package #2		
Time	Sensor	Radius	DSD	Lethality	Pt	(0, 0)	(1, 0)	(0, 1)	Radius	DSD	Lethality	Pt	Radius	DSD	Lethality	Pt	Radius	DSD	Lethality	Pt
0	N/A	N/A	N/A	N/A	N/A	**0.9**	**0.05**	**0.05**	0	0	0	0	900	0	0.8	2000	500	1600	0.6	30
									0.5	0.5	0.5	0.5	300	0.5	0.2	500	200	1000	0.2	20
1	Personnel	800	N/A	N/A	N/A	**0.608174**	**0.20984**	**0.181985491**	0.00125	0	0	0	864	0	0.8	2000	560	1600	0.6	30
									0.5	0.5	0.5	0.5	240	0.5	0.2	500	178.88544	1000	0.2	20
2	M21	600	1800	0.7	15	**1.05E-15**	**5.901E-13**	**1**	0.01625	0.005	0.693069	0.016648	639.0533	0.005	0.7058824	16.784894	590.47619	1783.4862	0.6941176	20.4
								(approximately)	0.499993	0.4999993	0.049752	0.499722	92.30769	0.4999993	0.0485071	14.993255	87.287156	287.34789	0.0485071	12

Based on intelligence acquisition, the IPB process, the mission, and the commander's intent, a maneuver commander may decide to reconnoiter an area for possible contamination. The commander uses available chemical reconnaissance units in addition to trained unit personnel to perform this mission. By confirming or denying the presence of chemical contamination, a unit may assume an appropriate level of protection prior to its location as well as employ the appropriate mobility tactic [11: 5-0-1].

Upon confirmation that a chemically contaminated area exists, the reconnaissance element performs a chemical survey to locate and mark its boundaries [11: 3-3]. The chemical survey is a critical action in determining possible bypass routes for follow-on forces. Several techniques are used to conduct surveys, all of which are mounted. Perhaps the most straight-forward technique is the box technique which determines the general dimensions (length and width) of the contaminated area [11: 8-2-3].

Bypassing confirmed, contaminated areas allows a unit to practice the first principle of NBC defense: contamination avoidance. Similarly, a unit encountering previously undetected contamination typically conducts bypass operations to limit the spread of contamination. In both of these situations, the unit attempts to avoid further degradation of unit efficiency. For this reason, bypassing is the most preferred tactic when encountering an area contaminated with persistent agents [5: 10-3,5].

Units cross or bull-through contaminated areas when the tactical situation or the terrain does not allow bypass operations to occur [5: 10-3]. Typically, these tactical situations occur during close operations when the unit does not have the time to conduct a chemical survey to identify possible bypass routes. The resulting effects of crossing an area contaminated with persistent agents are extensive decontamination requirements and degraded efficiency for extended periods of time. Therefore, a commander must carefully consider the risks before opting to bull-through these areas. Conversely, crossing is generally the preferred tactic when encountering non-persistent clouds due to the difficulty in defining their exact dimensions and their relatively short persistencies. Units assume full protection and continue to move through the chemical cloud. Upon dissipation of the cloud or completion of crossing, the unit readjusts its level of protection.

Each of these actions are equally important depending upon the unit mission and scenario and, thus, require modeling to some degree. The decision to conduct chemical reconnaissance and surveys is implicitly represented and is dependent upon the unit's current perception of chemical package existence as well as the tactic employed upon encountering them. Further discussion is provided in Section 3.9.4. However, units which encounter chemical packages require two orders to be modified to the JWAEP order stream: BYPASS and BULL-THROUGH. These orders are also proposed for engineer units when negotiating conventional obstacles but only within the support order stream [17: 39-40]. If a unit encounters a persistent chemical package and the model is in closed form operation mode, the default setting for unit tactic orders is BYPASS. This default setting is based on doctrinal tactics discussed previously.

3.9 Modeling The Effects of Chemical Weapons Use

A unit may experience the effects of chemical weapons use through three means: employment, bull-through, and discovery. The effects are dependent upon the chemical package and may include contamination, increased protective levels, and attrition.

Employment effects result from the initial dispersion of chemical package radii. Discovery effects result from contact with previously unknown chemical package. Bull-through effects occur upon a unit crossing chemical contamination. Additionally, units conducting movement require longer periods of time to negotiate chemical obstacles.

3.9.1 Employment Effects

As discussed in Section 3.5.2, the employment of chemical weapons utilizes the targeting process of the delivery weapon. Within JWAEP, the effects of area weapons are determined using the methodology developed in the Joint Theater Level Simulation (JTLS). This methodology determines the fraction of unit area covered by the weapon utilizing the aim point determined in the targeting process and the defined radii of the unit and area weapon. If partial overlap exists, the fraction of unit coverage is determined with the use of a uniform draw. The algorithm makes no attempt to determine the actual area of unit coverage. The possibility exists that this coverage may be quite large even though the partial overlap was quite small [4: 11-109-111]. Also, it can be shown that the fraction of unit coverage is indeed not uniformly distributed if the distance of the unit to the impact point is uniformly distributed.

In order to be more precise, the effects resulting from the initial dispersion of chemical packages will be determined utilizing the actual area of overlap. Using the same input requirements as the JTLS algorithm, the fraction of unit coverage, $Cov_{(i)}$, upon employment of chemical packages is calculated according to the following algorithm:

R_U = Unit radius
R_C = Initial dispersion radius of Chemical Package
d = the distance between the aim point and center mass of a unit
x = x axis value where intersection of unit and chemical package radii occurs upon initial dispersion of chemical package during employment
y = y axis value where intersection of unit and chemical package radii occurs upon initial dispersion of chemical package during employment
i = a separate encounter with a chemical package

1) If $d > R_U + R_C$, then no overlap exists and $Cov_{(i)} = 0$.

Otherwise.

2) If $R_U > R_C + d$, then R_U totally encompasses R_C and $Cov_{(i)} = \dfrac{\pi * R_C^2}{\pi * R_U^2}$

Otherwise.

3) If $R_U < R_C - d$, then R_C totally encompasses R_U and $Cov_{(i)} = 1$.

Otherwise.

4) Determine $$y = \left[\frac{R_U + d^2 - R_C}{2 \cdot d}\right] \tag{4}$$

$$x = \sqrt{R_U^2 - y^2} \tag{5}$$

5) If $0 \le y \le d$, then

$$Cov_{(i)} = \frac{\left[\begin{array}{l}\left[.5*\left(x*\sqrt{R_U^2 - x^2} + R_U^2 * \sin^{-1}\left(\frac{x}{R_U}\right)\right) - .5*\left(-x*\sqrt{R_U^2 - x^2} + R_U^2 * \sin^{-1}\left(\frac{-x}{R_U}\right)\right)\right] + \\ \left[.5*\left(x*\sqrt{R_C^2 - x^2} + R_C^2 * \sin^{-1}\left(\frac{x}{R_C}\right)\right) - .5*\left(-x*\sqrt{R_C^2 - x^2} + R_C^2 * \sin^{-1}\left(\frac{-x}{R_C}\right)\right)\right]\end{array}\right] - 2*d*x}{\pi * R_U^2} \tag{6}$$

6) If $y \geq d$, then

$$\mathrm{Cov}_{(i)} = \frac{\pi * R_C^2 - \left[\begin{matrix} \left[.5*\left(x*\sqrt{R_C^2 - x^2} + R_C^2 * \sin^{-1}\left(\frac{x}{R_C}\right)\right) - .5*\left(-x*\sqrt{R_C^2 - x^2} + R_C^2 * \sin^{-1}\left(\frac{-x}{R_C}\right)\right)\right] - \\ \left[.5*\left(x*\sqrt{R_U^2 - x^2} + R_U^2 * \sin^{-1}\left(\frac{x}{R_U}\right)\right) - .5*\left(-x*\sqrt{R_U^2 - x^2} + R_U^2 * \sin^{-1}\left(\frac{-x}{R_U}\right)\right)\right] \end{matrix} \right] - 2*d*x}{\pi * R_U^2} \quad (7)$$

7) If $y \leq 0$, then

$$\mathrm{Cov}_{(i)} = \frac{\pi * R_U^2 + \left[\begin{matrix} \left[.5*\left(x*\sqrt{R_C^2 - x^2} + R_C^2 * \sin^{-1}\left(\frac{x}{R_C}\right)\right) - .5*\left(-x*\sqrt{R_C^2 - x^2} + R_C^2 * \sin^{-1}\left(\frac{-x}{R_C}\right)\right)\right] - \\ \left[.5*\left(x*\sqrt{R_U^2 - x^2} + R_U^2 * \sin^{-1}\left(\frac{x}{R_U}\right)\right) - .5*\left(-x*\sqrt{R_U^2 - x^2} + R_U^2 * \sin^{-1}\left(\frac{-x}{R_U}\right)\right)\right] \end{matrix} \right] - 2*d*x}{\pi * R_U^2} \quad (8)$$

Upon determining partial overlap exists, the algorithm positions the unit center of mass at an origin in Cartesian space and the aim point on the corresponding y-axis. Equations (4) and (5) determine the point of intersection of the two radii. Finally, Equations (6), (7), and (8) utilize this intersection point to determine the actual area of overlap using a closed form solution of the integration of the area between two curves. Appendix E contains the derivations for each of these equations and Figure 3 illustrates the various states of overlap as well as the corresponding algorithm line to use.

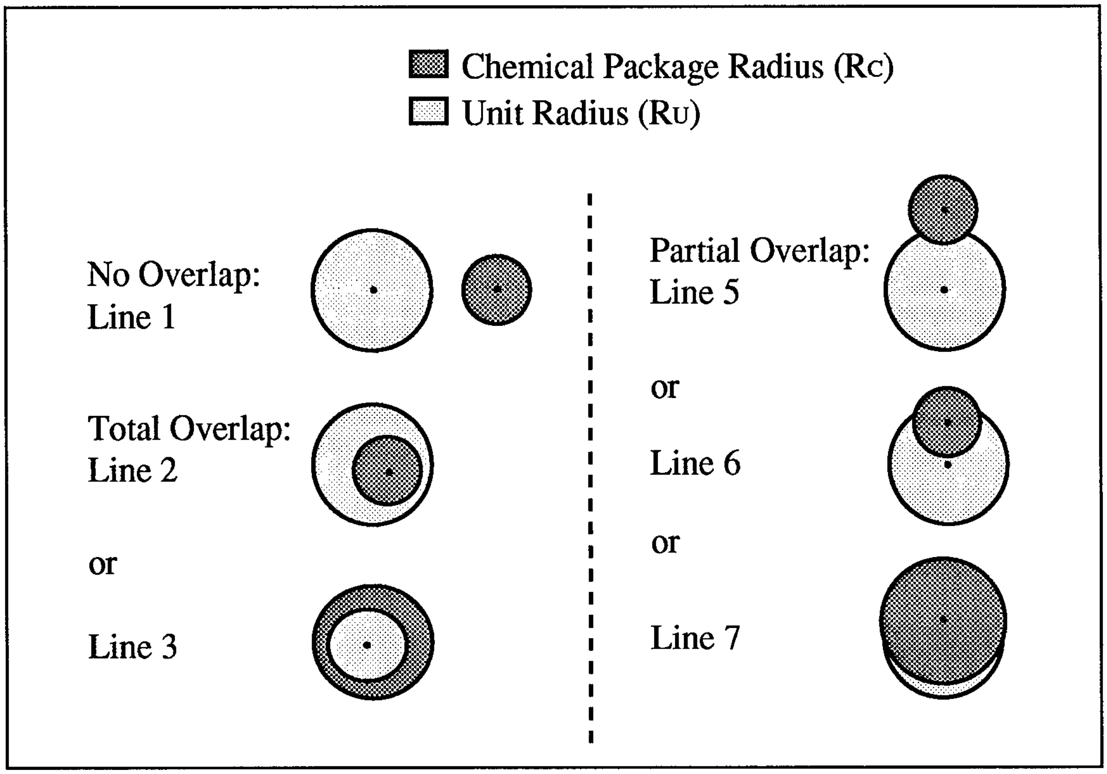


Figure 3 Unit Coverage Due to Initial Dispersion Upon Employment

Using Equations (4) through (8), the number of personnel losses associated with the employment of chemical packages, $Attr_{Employ}$, are computed with the following additional variable definitions:

$Attr_{DL}$ = the number of personnel losses due to the initial dispersion or discovery of chemical packages
$Attr_{DWH}$ = the number of personnel losses due to the downwind hazard of non-persistent chemical packages
L = the lethality of the chemical package
L_{FProt} = the lethality reduction factor for personnel in full protection
L_{PProt} = the lethality reduction factor for personnel in partial protection
PS = the current personnel strength of the unit prior to the chemical package encounter
SCALE = the scaling factor used to determine the fraction of unit contained within the downwind hazard area subject to downwind hazard losses
i = a separate encounter with a chemical package

The equation for employment losses, $Attr_{Employ}$, is depicted:

$$Attr_{Employ\,(i)} = Attr_{DL\,(i)} + Attr_{DWH\,(i)} \tag{9}$$

where

$$Attr_{DL\,(i)} = Cov_{(i)} * PS * L * (NProt_{Overall} + PProt_{Overall} * L_{PProt} + FProt_{Overall} * L_{FProt}) \tag{10}$$

$$Attr_{DWH\,(i)} = [FProt_{(i)} * SCALE - Cov_{(i)}] * L * L_{FProt} * PS \tag{11}$$

Equation (10) utilizes the fractions of unit protection at the time of the chemical strike while Equation (11) utilizes the fraction of unit forced to assume full protection due to the downwind hazard of non-persistent chemical packages. Determining this fraction as well as the parameter SCALE is discussed later in this section. Since all effects of chemical weapons use are determined assuming mathematical independence, no attempt is made to track which part of a unit is covered during employment as well as which parts are in protective levels. Therefore, Equation (10) assumes that a proportional amount of personnel are in the protective levels within the unit coverage as are in the unit overall.

The fraction of unit contaminated, $Cont_{(i)}$, from a persistent chemical package due to initial dispersion upon employment is depicted:

$$Cont_{(i)} = Cov_{(i)} \tag{12}$$

Recall, non-persistent agents produce significant vapor hazards but negligible contamination. Equation (12) assumes that only equipment within the dispersion radius of persistent chemical packages is contaminated. Since chemical warning and reporting procedures are implicitly represented, the remaining unit equipment is given knowledge of the contaminated area and thereby avoids further contamination. This value, as well as its associated persistency, will be retained for future computations to determine the overall fraction of unit contaminated upon subsequent contamination.

The final effect from the employment of chemical weapons is an adjustment in the unit protective level. Commanders will adjust the protective level of unit in response to the risk associated with the chemical package. Section 3.4.2 provides both a discussion and illustration of adjusting a unit's protective level. Generally, all unit personnel will not assume full protection unless the chemical package has the potential of encompassing the entire unit. This potential is normally associated with non-persistent chemical packages since persistent chemical packages are not capable of movement. However, personnel within the persistent contamination area must also assume a higher level of protection. Therefore, the determination of the fraction of unit that assumes full protection in response to the employment of chemical packages and for how long is dependent upon the chemical package type: persistent or non-persistent.

The fraction of unit that must assume full protection as a result of a persistent chemical package strike utilizes Equation (12) and is depicted:

$$FProt_{(i)} = Cont_{(i)} \qquad (13)$$

As stated earlier, the hazard associated with persistent chemical packages is contained within the dispersion radius and unable to move. This value, as well as its associated persistency, will be retained for future computations to determine the overall fraction of unit in full protection upon subsequent encounters with chemical packages.

The determination of the fraction of unit and length of time that a unit must assume full protection as a result of a non-persistent chemical package strike is more complicated due to the ability of the package to move on the battlefield. However, several assumptions can be made to simplify this determination.

1) Non-persistent chemical packages are employed towards the upwind side of a unit in order to maximize their effects [8: 3-1, 7: 1-6].

2) If a unit is moving, it continues to move or bull-through the non-persistent cloud. Otherwise, the unit remains stationary until the cloud is no longer over the unit position.

3) The downwind hazard area extends from one side of a unit formation to the other and personnel within this hazard area assume full protection [8: 3-12].

The fraction of unit that assumes full protection is computed with the following parameter definitions:

θ = the angle used to determine the parameters for calculating the fraction of unit forced into full protection due to encounters with non-persistent chemical packages (degrees)
SPEED = the speed used to determine both the amount of time a unit remains in full protection due to a non-persistent cloud encounter and the adjusted penetration distance (discussed in Section 3.9.2) due to discovery (meters per minute)
TIME = the period of time the fraction of unit forced into full protection must remain in full protection due to a chemical package encounter (minutes)
$Cloud_{Orient}$ = the global wind direction (degrees)
$Unit_{Orient}$ = the direction in which the unit is oriented (degrees)
Facet = the dimension of a unit that initially encounters a chemical package
Other Facet = the dimension of a unit that does not initially encounter a chemical package
Length = a unit's formation length across its front (meters)
Width = a unit's formation width or depth (meters)
LWS = the local wind speed (meters per minute)
UMR = the instantaneous unopposed movement rate for a unit (meters per minute)
P_t = the remaining persistency of a chemical package (minutes)
DSD = the downwind stretch distance of a non-persistent chemical package

The appropriate increase in the unit level of protection is computed by determining the direction of cloud travel, $Cloud_{Orient}$, in relation to four defined unit sectors. These sectors are defined by extending the diagonals of a unit formation and calculating the angle θ depicted in Figure 4.

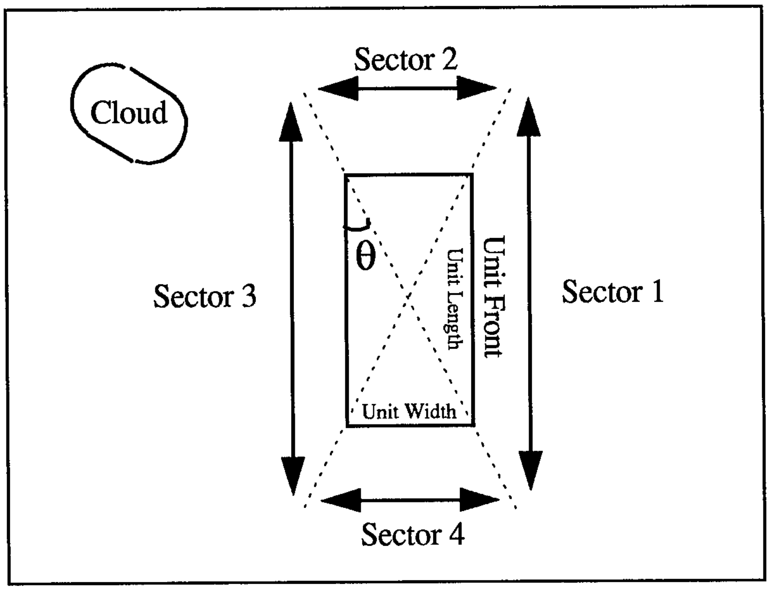


Figure 4 Unit Sectors

The angle θ is computed according to Equation (14).

$$\theta = \text{Round}[\arctan(\text{Width} / \text{Length}) * (180 \text{ degrees} / \pi)] \quad (14)$$

Using the angle θ and the direction in which the unit front is oriented, $Unit_{Orient}$, the degree range of each sector is determined. This range represents the range of wind direction in which a non-persistent cloud would first encounter a particular unit facet assuming it were employed on the upwind side of the unit. Therefore, by determining which sector the cloud direction of travel fits into, the appropriate downwind hazard area can be determined.

The parameter SPEED is dependent upon whether the unit is stationary or moving and the direction of the wind. If the unit is stationary, the SPEED is equivalent to the local wind speed, LWS, regardless of the direction of the wind. However, if the unit is moving, the SPEED is dependent upon the direction of the wind in relation to the orientation of the unit. With a crosswind, the local wind speed is used. Otherwise, the SPEED is computed as either the sum or absolute difference of the local wind speed and unit speed depending upon whether the unit is traveling against or with the wind direction, respectively. It is important to note that the unit speed is the instantaneous speed of the unit after the increase in unit protection level has been determined. However, when determining the penetration distance used to determine discovery effects, the speed of the unit prior to encountering the chemical package is utilized. Subsequent discovery effect computations utilize the unit speed after the increase in unit protection.

The parameter TIME determines the length of time the fraction of unit must remain in full protection due to a chemical package encounter and is computed according to Equations (15) and (16):

$$\text{TIME} = \text{Min}\{P_t, [(\text{Other Facet} + 2 * R_C + \text{DSD}) / \text{SPEED}]\} \tag{15}$$

$$\text{TIME} = \text{Min}\{P_t, [(\text{Other Facet} + 2 * R_C + \text{DSD}) / \text{SPEED}], [(.5 * \text{Facet} + R_C) / \text{UMR}]\} \tag{16}$$

Equations (15) and (16) determine the minimum of the remaining persistency of the cloud at the time of the encounter and the time required for the cloud to completely clear the unit formation by either the cloud traversing the unit or the unit crossing the cloud. Equation (16) is used if the unit is moving and encounters a crosswind.

The parameter SCALE is used to determine the fraction of unit contained within the downwind hazard area that is subject to downwind hazard losses and is computed according to Equations (17) and (18):

$$SCALE = Min[1, (P_t * SPEED) / (Other\ Facet)] \quad (17)$$

$$SCALE = Min\{1, Min[(P_t * SPEED) / (Other\ Facet), (.5 * Facet + R_C) * SPEED / (UMR * Other\ Facet)]\} \quad (18)$$

Although the downwind hazard area extends through the unit, whether the cloud traverses this distance is dependent upon its remaining persistency, the time required for the front of the cloud to traverse the length of the downwind hazard, and the time required for the unit to cross the cloud. The cloud traverses the entire downwind hazard area if this time is less than the cloud's remaining persistency and/or the time required for the unit to cross the cloud, depending on the unit posture and wind direction. If the time required for the cloud to traverse the downwind hazard is greater than the others, then only a fraction of the downwind hazard area is actually covered by the cloud. This fraction represents the parameter SCALE and is determined by dividing the cloud's remaining persistency and/or the time required to cross the cloud by the time required for the cloud to traverse the downwind hazard area.

Table 13 depicts the method in which sector ranges are determined, their corresponding unit facet, the speed used to determine the length of time the fraction of unit must remain in full protection as well as the amount of overlap during a surprise encounter with a chemical package (discussed in Section 3.9.2), the scale factor used to determine downwind hazard losses, and the length of time the fraction of unit assuming full protection must remain in that level of protection.

Table 13 Parameters for Downwind Hazard and Discovery Computations

Sectors	Facet	SPEED	SCALE	TIME
Non-Persistent:				
Unit Moving				
$Unit_{Orient}$ + (270+θ) to $Unit_{Orient}$ + (90-θ)	Length	LWS + UMR	Eqn (17)	Eqn (15)
$Unit_{Orient}$ + (90-θ) to $Unit_{Orient}$ + (90+θ)	Width	LWS	Eqn (18)	Eqn (16)
$Unit_{Orient}$ + (90+θ) to $Unit_{Orient}$ + (270-θ)	Length	|UMR - LWS|	Eqn (17)	Eqn (15)
$Unit_{Orient}$ + (270-θ) to $Unit_{Orient}$ + (270+θ)	Width	LWS	Eqn (18)	Eqn (16)
Unit Stationary				
$Unit_{Orient}$ + (270+θ) to $Unit_{Orient}$ (90-θ)	Length	LWS	Eqn (17)	Eqn (15)
$Unit_{Orient}$ + (90-θ) to $Unit_{Orient}$ + (90+θ)	Width	LWS	Eqn (17)	Eqn (15)
$Unit_{Orient}$ + (90+θ) to $Unit_{Orient}$ + (270-θ)	Length	LWS	Eqn (17)	Eqn (15)
$Unit_{Orient}$ + (270-θ) to $Unit_{Orient}$ + (270+θ)	Width	LWS	Eqn (17)	Eqn (15)
Persistent				
Unit Stationary and Moving	Length	UMR	N/A	P_t

Using Table 13, the fraction of unit that assumes full protection, FProt, due to the employment of non-persistent chemical packages is computed according to Equation (19).

$$FProt_{(i)} = [Min(Facet, 2 * R_C) * Other\ Facet] / (Width * Length) \qquad (19)$$

This value, as well as its associated TIME, will be retained for future computations to determine the overall fraction of unit in full protection upon subsequent encounters with chemical packages.

The following example of determining the number of personnel losses and the fraction of unit that assumes full protection due to non-persistent chemical packages illustrates the application of Equations (4) through (19) as well Table 13. The enemy employs a non-persistent chemical package on an armored brigade in partial protection conducting movement along an arc in the direction of 20 degrees. The distance between the aim point and center mass of unit is 470 meters. The unopposed movement rate in no protection is 22 km/hr and the effectiveness degradation factors for unopposed movement in partial and full protection are 0.9 and 0.75, respectively. The current strength of the brigade is 1500 personnel with a formation area of 500 meters wide and 2000 meters in length. The attributes of the chemical package for the current weather conditions are the following: radius is 100 meters, downwind stretch distance is 1500 meters, the persistency is 20 minutes, and the lethality is 0.9. The local wind speed is 10 km/hr and direction is 280 degrees. The lethality reduction factors for partial protection and full protection are .8, and .05, respectively. The defined parameters are assigned the following values:

$d = 470$ meters
Length = 2000 meters
Width = 500 meters
$Unit_{Orient} = 20$ degrees
PS = 1500 personnel
$R_U = 564.2$ meters
$R_C = 100$ meters
DSD = 1500 meters
$P_t = 20$ minutes
$Cloud_{Orient} = 280$ degrees
LWS = 10 km/hr = 166.67 meters per minute
Movement rate in no protection = 22 km/hr = 366.67 meters per minute
$Eff_{PProt} = 0.9$
$Eff_{FProt} = 0.75$
$NProt_{Overall} = 0$
$PProt_{Overall} = 1.0$
$FProt_{Overall} = 0.0$
$L_{PProt} = .8$
$L_{FProt} = .05$

Using Equations (4), (5), and (7),

$$y=\left[\frac{R_U+d^2-R_C}{2\cdot d}\right] = 563 \qquad x=\sqrt{R_U^2-y^2} = 36.8$$

$$Cov_{(i)}=\frac{\pi * R_C^2-\left[\begin{matrix}\left[.5*\left(x*\sqrt{R_C^2-x^2}+R_C^2*\sin^{-1}\left(\frac{x}{R_C}\right)\right)-.5*\left(-x*\sqrt{R_C^2-x^2}+R_C^2*\sin^{-1}\left(\frac{-x}{R_C}\right)\right)\right]- \\ \left[.5*\left(x*\sqrt{R_U^2-x^2}+R_U^2*\sin^{-1}\left(\frac{x}{R_U}\right)\right)-.5*\left(-x*\sqrt{R_U^2-x^2}+R_U^2*\sin^{-1}\left(\frac{-x}{R_U}\right)\right)\right]\end{matrix}\right]-2*d*x}{\pi * R_U^2}$$

$Cov_{(1)} = .031$

Using Equation (10),

$Attr_{DL\,(1)} = Cov_{(1)} * PS * L * (NProt_{Overall} + PProt_{Overall} * L_{PProt} + FProt_{Overall} * L_{FProt})$
$Attr_{DL\,(1)} = .031 * 1500 * .9 * (0 + 1 * .8 + 0 * .05)$
$Attr_{DL\,(1)} = 33.48$ personnel

Using Equation (14),

θ = Round[arctan(Width / Length) * (180 degrees / π)]
θ = Round[arctan(500 / 2000) * (180 degrees/3.14159)]
θ = 14.036 degrees ≈ 14 degrees

Using Table 13,

Facet = Width = 500 meters
Other Facet = Length = 2000 meters
SPEED = LWS = 166.67 meters per minute

Using Equation (19),

$FProt_{(1)}$ = {Min[Facet, 2 * R_C] * Other Facet} / (Width * Length)
$FProt_{(1)}$ = {Min[500, 2*100] * 2000}/ (500 * 2000)
$FProt_{(1)}$ = 0.4

Therefore, the updated status of the unit protective levels is:

$$NProt_{Overall} = 0$$
$$PProt_{Overall} = 0.6$$
$$FProt_{Overall} = 0.4$$

Using Equation (1),

$$Eff_{Overall} = [(NProt_{Overall}) + (PProt_{Overall})*(Eff_{PProt}) + (FProt_{Overall})*(Eff_{FProt})]$$
$$Eff_{Overall} = [(0) + (0.6) * (0.9) + (0.4) * (0.75)]$$
$$Eff_{Overall} = 0.84$$

To determine the instantaneous unit speed, UMR, the unit speed in no protection is multiplied times the unit effectiveness:

$$UMR = 366.67 * 0.84$$
$$UMR = 308 \text{ meters per minute}$$

Using Table 13,

$$SCALE = Min\{1, Min[(P_R * SPEED) / (Other Facet), (.5 * Facet + R_C) * SPEED / (UMR * Other Facet)]\}$$
$$SCALE = Min\{1, Min[(20 * 166.67) / 2000, (.5 * 500 + 100) * 166.67 / (308 * 2000)]\}$$
$$SCALE = Min\{1, Min[1.67, .095]\}$$
$$SCALE = .095$$

$$TIME = Min\{P_t, [(Other Facet + 2 * R_C + DSD)/ SPEED], [(.5 * Facet + R_C) / UMR]\}$$
$$TIME = Min\{20, [(2000 + 2 * 100 + 1500) / 166.67], [(0.5 * 500 + 100) / 308]\}$$
$$TIME = Min\{20, 22.2, 1.14\}$$
$$TIME = 1.14 \text{ minutes}$$

Using Equations (11) and (9),

$$Attr_{DWH\,(1)} = [FProt_{(1)} * SCALE - Cov_{(1)}] * L * L_{FProt} * PS$$
$$Attr_{DWH\,(1)} = [.4 * .095 - .031] * .9 * .05 * 1500$$
$$Attr_{DWH\,(1)} = .473 \text{ personnel}$$

$$Attr_{Employ\,(1)} = Attr_{DL} + Attr_{DWH}$$
$$Attr_{Employ\,(1)} = 33.48 + .473$$
$$Attr_{Employ\,(1)} = 33.953 \text{ personnel}$$

Figure 5 provides an illustration of this example.

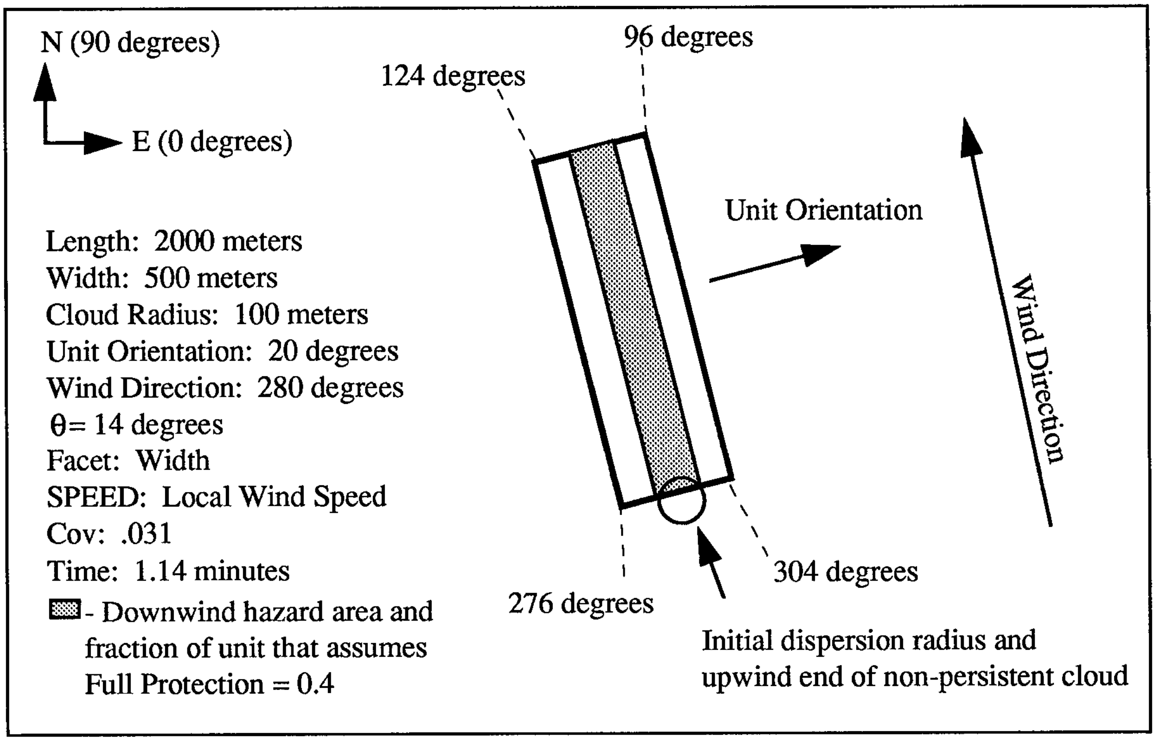


Figure 5 Illustration of Determining Attrition and FProt Due to Employment

Thus, the unit loses 33.953 personnel while 40 percent (0.4) of the remaining personnel must assume full protection for 1.14 minutes as a result of the employment of a non-persistent chemical package.

3.9.2 Discovery Effects

Discovery effects occur as a result of a unit encountering previously unknown chemical packages. Upon a "surprise" encounter, the chemical package penetrates the unit formation. The penetration distance is dependent upon numerous parameters, many of which are the same used to determine employment effects. However, unlike employment effects, discovery effects account for the ability of a unit to detect chemical packages by adjusting the distance that the chemical package penetrates the unit formation.

Using Table 13, the raw penetration distance from a "surprise" encounter with a chemical package, $Dist_{Raw\ Pen}$, is depicted:

$$Dist_{Raw\ Pen} = SPEED * (1\ minute) \tag{20}$$

Equation (20) assumes that discovery effects from non-persistent chemical packages result from the downwind end of a non-persistent cloud since they are normally employed on the upwind side of a unit and have fairly small persistencies. One minute represents the maximum length of time before unit personnel would notice the presence of chemical agents within their formation if no detection equipment were available. This value may be adjusted depending upon the level of training personnel receive in recognizing the effects of chemical agents. Assuming units have equivalent detection capabilities, the raw penetration distance is then adjusted according to whether the unit is stationary or moving and the chemical package. Typically, stationary units possess a stand-off detection capability due to the positioning of detection equipment outside their formation. Although it takes some time for the equipment to sound an alert, this positioning greatly reduces the possible penetration distance of non-persistent clouds. Conversely, units conducting movement cannot utilize this stand-off capability and, therefore, the penetration distance may be larger. Regardless of the unit posture, standard chemical detection equipment does not detect all types of agents. Appendix B describes the various types of detection equipment normally found within U.S. Army units.

Within JWAEP, arguments to a distribution are computed as an expression of the form Ax + B where x is a value provided by JWAEP and A and B are provided by the user. For example, the speed of a unit may be computed as a random draw from a uniform distribution with a minimum of (0.95*true.speed)+0.0 and maximum of (1.05*true.speed)+0.0. In this example, two sets of parameters are given. The first set of parameters set A equal to 0.95 and B equal to 0.0. Likewise, the second set of parameters set A equal to 1.05 and B equal to 0.0. The variable true.speed corresponds to the x value and is provided by JWAEP [31: 22-23].

The adjustment of the raw penetration distance occurs in a similar manner to the example just provided. The adjusted penetration distance, $Dist_{Adj\ Pen}$, is depicted:

$$Dist_{Adj\ Pen} = U[(A_1 * Dist_{Raw\ Pen} + B_1), (A_2 * Dist_{Raw\ Pen} + B_2)] \quad (21)$$

Table 14 provides a sample of parameters for several chemical packages based upon the unit posture.

For example, the stand-off detection capability of a unit is represented for a non-persistent G nerve agent (chemical package NP-G) by limiting the adjusted penetration

Table 14 Sample Adjustment Parameters for Penetration Distance

	Chemical Packages			
Unit Posture	NP - G	P - VX	NP - CK	P - L
1. Stationary				
Parameter 1	A=0.0 B=0.0	N/A	A=0.25 B=0.0	N/A
Parameter 2	A=0.5 B=0.0	N/A	A=1.0 B=0.0	N/A
2. Moving				
Parameter 1	A=0.25 B=0.0	A=0.0 B=0.0	A=0.25 B=0.0	A=0.0 B=0.0
Parameter 2	A=1.0 B=0.0	A=1.0 B=0.0	A=1.0 B=0.0	A=1.0 B=0.0

distance between zero and half of the raw penetration distance. Conversely, a unit normally does not possess a stand-off detection capability for a non-persistent cyanogen chloride (chemical package NP-CK). Therefore, the penetration distance may be adjusted between one-fourth and the full raw penetration distance depending upon when the personnel recognize the chemical hazard. These parameters may be modified to represent an increase or decrease in the detection capability of a unit.

Determining the fraction of unit coverage due to employment of chemical packages utilizes the existing methodologies within JWAEP for determining the effects of area weapons. However, if no unit is contained within the initial dispersion radius of the chemical package, there are no direct effects as a result of its employment and the methodology cannot be utilized. Thus, determining the fraction of unit covered within the adjusted penetration distance upon discovery of a chemical package requires a different algorithm. Using the adjusted penetration distance calculated in Equation (21), the fraction of unit covered by the adjusted penetration distance is determined with the following additional variables:

ES = the current equipment strength of the unit prior to the chemical package encounter. For light infantry and special operations forces units, this value is equal to the current personnel strength

Density = the density of a unit or the number of pieces of equipment which occupy one square meter of space. Expressed as number of pieces of equipment per square meter (Equation 22).

$Lines_{Aff}$ = the number of unit lines affected by the adjusted penetration distance

$Line_{Density}$ = the density of a unit across it's lines (number of pieces of equipment per linear meter)

$Dist_{Lines}$ = the distance between unit lines within a unit formation (meters)

The density of a unit at any given moment, Density, is depicted:

$$Density = ES / (Width * Length) \quad (22)$$

Assuming a unit does not receive either personnel or equipment replacements, the unit density will decrease upon equipment losses due to the constant size of a unit formation.

Similarly, the number of soldiers per vehicle will also decrease due to the capability of chemical packages to attrit personnel but not equipment. Hence, Equation (22) realistically assumes that a unit uniformly redistributes its personnel and equipment throughout its formation.

Within a unit formation, equipment is typically positioned in echelons or lines. These lines are not linearly arranged across the battlefield, however, they do occupy some nonlinear space in depth for command and control purposes. Assuming a uniform distribution of a unit's equipment throughout its formation, the distance between lines of a unit, $Dist_{Lines}$, is defined [17: 60-61]:

$$Dist_{Lines} = [1/\ Density]^{.5} \tag{23}$$

Since equipment is uniformly distributed within a unit formation, the distance between equipment across unit lines will equal the linear distance between unit lines. Thus, the density of a unit across its lines, $Line_{Density}$, is defined [17: 61]:

$$Line_{Density} = [1/\ Dist_{Lines}] \tag{24}$$

The number of unit lines affected by the adjusted penetration distance, $Lines_{Aff}$, is computed using Table 13 according to Equation (25).

$$Lines_{Aff} = Trunc\{1 + Min[Dist_{Adj\ Pen},\ Other\ Facet]/\ Dist_{Lines}\} \tag{25}$$

The fraction of unit covered by the adjusted penetration distance upon discovery of a chemical package, $Cov_{(i)}$, is determined according to the following algorithm:

j = a unit line = 1... $Lines_{Aff}$
M_j = distance from chemical package radius center to line j
D_j = the possible distance of line j affected by the adjusted penetration distance
N_j = half of D_j

1) Determine $M_1 = R_C - Dist_{Adj\ Pen}$
2) If $M_j \leq 0$ and Facet $\geq 2*R_C$, then
   $D_j = 2*R_C$
   Otherwise, D_j = Facet and go to step 5
3) Determine $N_j = [(R_C)^2 - (M_j)^2]^{.5}$
4) $D_j = Min[Facet, 2*N_j]$
5) If $j = Lines_{Aff}$, then

$$Cov_{(i)} = \left(\sum_{1}^{Lines_{Aff}} D_j * Line_{Density} \right) / ES \qquad (26)$$

6) $M_{j+1} = M_j + Dist_{Lines}$ and go to step 2

The algorithm realistically assumes that the enemy employs chemical packages so that either the full width of the unit facet or the full width of the chemical package is encountered.

The number of personnel losses associated with the discovery of chemical packages, $Attr_{Discovery}$, are computed utilizing Equations (10) and (11) defined on page 58:

$$Attr_{Discovery\ (i)} = Attr_{DL\ (i)} + Attr_{DWH\ (i)} \qquad (27)$$

Equation (27) is essentially the same as Equation (9) for employment losses. The difference is the algorithms in which the fraction of unit coverage, $Cov_{(i)}$, is determined.

The fraction of unit contaminated and the fraction of unit that must assume full protection due to the discovery of a persistent chemical package as well as the fraction of unit that must assume full protection due to the discovery of a non-persistent chemical package are computed utilizing the same equations used for determining employment effects. These equations are depicted in Table 15.

Table 15 Mapping Discovery Effects to Employment Effects

Package Type	Fraction of Unit	Equation	Page
Persistent	$Cont_{(i)}$	12	60
Persistent	$FProt_{(i)}$	13	60
Non-Persistent	$FProt_{(i)}$	19	66

3.9.3 Bull-through Effects

As discussed in Section 3.8, a unit may have no other option but to cross a chemically contaminated area. The effects of crossing a non-persistent chemical package are accounted for in either the employment or discovery effects depending upon how the chemical package was encountered. Therefore, bull-through effects only occur as a result of crossing persistent chemical packages.

Determining the effects of bulling-through chemical contamination are relatively simple in comparison to employment or discovery effects due to the inability of persistent chemical packages to move. Additionally, as the unit crosses, the entire depth of the unit is affected. Thus, the fraction of unit covered due to bulling-through persistent chemical packages, $Cov_{(i)}$, is depicted:

$$Cov_{(i)} = \text{Min}[\text{Length}, (2 * R_C)] / \text{Length} \qquad (28)$$

Again, Equation (28) assumes that the enemy employs chemical packages so that either the full width of the unit front or the full width of the chemical package is encountered.

The number of personnel losses due to bulling-through persistent chemical packages, $Attr_{Bull}$, is depicted:

$$Attr_{Bull\,(i)} = [Cov_{(i)} - (Cov_{(i)} \text{ from Discovery})] * L * L_{FProt} * PS \qquad (29)$$

Equation (29) computes the personnel losses for a unit crossing a known or previously unknown contaminated area. If the unit has previous knowledge of the contaminated area, the fraction of unit covered due to discovery and its related attrition are equal to zero. Also, Equation (29) uses only the lethality reduction factor for full protection since units will cross contamination in this protective level.

The fraction of unit that receives contamination as well as the fraction of unit that assumes full protection as a result of bulling-through a persistent chemical package are computed utilizing the same equations used for determining employment effects. These equations are depicted in Table 16.

Table 16 Mapping Bull-Through Effects to Employment Effects

Fraction of Unit	Equation	Page
$Cont_{(i)}$	12	60
$FProt_{(i)}$	13	60

If the unit bulls-through chemical contamination after discovery, the fraction of unit contaminated and fraction of unit that assumes full protection due to discovery is removed and replaced with the value computed for bull-through effects. These values, as well as their associated persistency and TIME, are retained for future computations to determine the overall status of the unit upon subsequent contamination. It is important to note that fraction of unit assuming full protection must be included in the calculation of the instantaneous unit speed to determine the length of time to cross the contaminated area.

3.9.4 Determining the Time Required to Negotiate Chemical Packages

The time required for a unit to negotiate a chemical package is a function of the type of chemical package, the size of the package, the tactic employed, and the perception of the encountering unit. Assuming nonclose combat conditions, units will bull-through non-persistent chemical packages and bypass persistent chemical packages. Therefore, algorithms are provided for both tactics.

As discussed previously, the chemical package intelligence data is fused and a probability vector of existence, location, and size is generated to form a perception of enemy chemical weapons use. The probability vector is only a perception until a unit actually encounters a chemical package or it has been confirmed or denied by chemical reconnaissance. However, a unit conducting chemical reconnaissance disrupts its momentum. Likewise, an increase in the unit level of protection also has the same effect. Thus, a commander must carefully consider when to conduct chemical reconnaissance or increase the unit level of protection. This decision is represented through the use of a perception threshold. The user defines the aggregated perception level upon which a unit will conduct some type of action in response to the perceived chemical threat. The perception threshold represents the amount of risk a commander is willing to accept. Lower values represent risk aversion while higher values correspond to risk seeking. The aggregated perception is the sum of all the perceptions of chemical packages for a particular location regardless of the type of chemical package. For example, a perception vector for a specific location may be the following:

0.35	Nothing Present
0.35	Persistent VX
0.2	Non-persistent G
0.1	Non-persistent CK

The aggregated perception would equal 0.65. If this value were higher than the perception threshold, the unit would take an appropriate action depending upon the largest aggregated perceived threat by chemical package type: persistent or non-persistent. Otherwise, the unit would continue with its mission. Using this example, the aggregated perception levels for each type of package are 0.35 for persistent and 0.3 for non-persistent. Thus, the largest perceived threat is from a persistent chemical package; the unit halts just prior to the location and conducts a chemical reconnaissance. If the most likely threat is a non-persistent chemical package, JWAEP determines if an intercept would occur between the unit and the chemical package using the perceived attributes and the current weather conditions. If no intercept is determined to occur, the unit takes no action. However, if an intercept is determined to occur, the unit assumes full protection just prior to the intercept location thereby significantly reducing casualties.

If no contamination is found by the chemical reconnaissance, the unit continues its movement in its current state and the perception of chemical weapons use at that location is removed from the simulation. If contamination was found, the chemical reconnaissance element conducts a chemical survey to mark the contaminated area and determine if a bypass operation is feasible. If bypassing is possible, the unit conducts a bypass operation. If bypassing is not possible, the unit conducts a bull-through operation. It is assumed that the reconnaissance elements conduct sampling without error.

The algorithms computing the time required to negotiate an encounter with chemical obstacles utilize the following variable definitions:

T_{Dis} = the discovery time associated with encountering previously unknown persistent chemical packages (minutes)
T_R = the time required to conduct a chemical reconnaissance of a perceived persistent chemical package (minutes)
T_{Sur} = the time required to conduct a chemical survey of a persistent chemical package (minutes)
T_{Sam} = the time required to complete a chemical survey sample (minutes)
D_{BS} = the distance between survey samples (meters)
T_{BS} = the time required to travel between samples (minutes)
T_{By} = the time required to bypass a persistent chemical package (minutes)
T_{Bull} = the time required to bull-through a chemical package (minutes)

Discovery time, $T_{Dis\,(i)}$, is a fixed time expressed in minutes and reflects a 10 minute command and control delay associated with making a decision to bypass or bull-through the persistent chemical package.

The reconnaissance time, $T_{R\,(i)}$, only applies if the aggregated perception threshold is reached and the aggregated perceived chemical package threat is persistent. The reconnaissance time is a fixed time expressed in minutes and reflects a 30 minute execution time to perform chemical reconnaissance at the perceived location.

The survey time, $T_{Sur\,(i)}$, only applies if the chemical reconnaissance detects chemical contamination or the unit employs a bypass tactic upon encountering a previously unknown contaminated area. The survey time is expressed in minutes and is dependent upon the size of the contamination area. The survey time is depicted in Equation (30).

$$T_{Sur\,(i)} = (T_{BS} + T_{Sam}) * [(4 * R_C) / D_{BS}] \qquad (30)$$

where

T_{Sam} = 5 minutes per sample [8: 5-4]
D_{BS} = every 200 meters [11: 8-3]
$$T_{BS} = D_{BS} / UMR \qquad (31)$$

The survey utilizes the box technique [11: 8-2] and the parameter T_{BS} is computed using the unit movement rate as if it were entirely in full protection. Using this rate portrays the elements conducting the survey in full protection.

Upon survey completion of previously unknown chemical contamination or the decision to avoid a known contaminated area, the unit conducts a bypass operation.

$$T_{By\,(i)} = (3 * R_C) / UMR \qquad (32)$$

The bypass time assumes that the unit encounters the contaminated area at the center of its front. Also, this equation uses the instantaneous speed of the unit after determining discovery effects, if applicable.

The bull-through time for crossing a chemical package only applies if the unit decides to employ a bull-through tactic or the survey determines that a bypass operation is not feasible. Since units always bull-through non-persistent chemical packages, a distinction must be made between chemical package types. The bull-through time algorithms for chemical package types are depicted in Equations (33) and (34).

Persistent: $$T_{Bull\,(i)} = (2 * R_C + \text{Width}) / \text{UMR} \quad (33)$$

Non-Persistent: $$T_{Bull\,(i)} = \text{TIME} \quad (34)$$

Again, both equations utilize the instantaneous speed of the unit after the bull-through effects have been determined.

Table 17 summarizes the various times associated with negotiating chemical packages and their applicability.

Table 17 Summary of Chemical Package Time Rules

Perception	Package Type and Unit Action	Total Time to Negotiate Encounter (i)
Known	Persistent (Bypass)	T_{By}
	Persistent (Bypass Unfeasible)	T_{Bull}
	Non-Persistent	TIME
≥Threshold	Persistent (Presence Denied)	T_R
	Persistent (Detect and Bypass)	$T_R + T_{Sur} + T_{By}$
	Persistent (Detect and Bull)	$T_R + T_{Sur} + T_{Bull}$
	Non-Persistent (No Encounter)	N/A
	Non-Persistent (Encounter)	TIME
<Threshold	Persistent (Bypass)	$T_{Dis} + T_{Sur} + T_{By}$
	Persistent (Bypass Unfeasible)	$T_{Dis} + T_{Sur} + T_{Bull}$
	Persistent (Bull)	$T_{Dis} + T_{Bull}$
	Non-Persistent	TIME

3.10 Modeling Decontamination of Chemical Contamination

As discussed previously, a unit receives contamination as a result of an encounter with a persistent chemical package. The presence of this contamination reduces the unit combat effectiveness by forcing personnel into a higher level of protection until the hazard no longer remains. Since persistent chemical packages have large persistencies, this degradation of effectiveness may continue for days and even weeks. Therefore, the restoration of combat power by decontamination efforts must occur quickly and as close to the area of contamination as possible.

3.10.1 Decontamination Assets

As discussed in Section 3.1, chemical units are not explicitly modeled. Rather, their assets are implicitly represented by associating an appropriate number of chemical "resources" to a maneuver force, as dictated by the maneuver force task organization. These resources include decontamination apparatuses contained within chemical decontamination units as well as those organic to the maneuver unit. Appendices A and B describe the standard decontamination assets within the U.S. Army and their normal distribution.

Within JWAEP, units are defined in terms of unit type. The data structure for each unit type consists of fields of special attributes which define the characteristics relevant to that unit type. These attributes include the function of a unit, its maximum support range, and the mapping of the organic air defense assets of the unit to the air defense system [31: 24]. Since decontamination assets are modeled as unit resources, it is logical to define their existence within the unit type data structure. Therefore, an additional field must be added to the unit type data structure which defines the number of decontamination resources a unit possesses: DECON RESOURCES.

In defining the number of decontamination resources for a unit type, the user must carefully consider the size of the unit. Within JWAEP, the typical maneuver unit is a brigade which normally consists of three battalions. Each battalion has an organic decontamination apparatus. Also, the brigade usually has a chemical decontamination unit assigned or attached. Normally, this unit contains three decontamination apparatuses. The total number of decontamination resources within the brigade is six. However, since units typically decontaminate by rotation, all the resources will not be used [9: 1-2, 3-1]. A brigade size unit will typically rotate one battalion through decontamination at a time. This battalion's organic decontamination asset, in conjunction with the chemical unit assets, will perform the decontamination. Hence, the number of decontamination resources available for unit decontamination equals four and not six. Therefore, the number of decontamination resources defined for a unit type equals the number of chemical unit assets plus the number of assets contained within unit type's subordinate element.

3.10.2 Decontamination Operations

As discussed in Section 2.2.3, three levels of decontamination efforts exist: immediate, operational, and thorough. Immediate decontamination efforts stop the penetration of chemical agents and are performed by the equipment operators who require no additional decontamination assets. Operational and thorough decontamination efforts are much more effective, however, they require decontamination apparatuses. Thus, these two levels of decontamination are modeled. Immediate decontamination is implicitly represented in the chemical package persistencies.

Personnel and equipment undergoing decontamination operations are rendered combat ineffective until the decontamination is completed. For this reason, decontamination normally occurs only if the unit is not engaged in close combat. Also, if the weathering time for the contamination is less than the time required for decontamination, the unit will not conduct decontamination operations. As mentioned previously, units will rotate their equipment through decontamination in order to maintain a force capable of close combat, if required. Since the typical maneuver unit is a brigade, the largest element conducting decontamination at one time would be a battalion or one-third of the brigade. This rule can also be applied to smaller or larger units. Therefore, decontamination operations utilize the following rules:

a) The unit is not engaged in close combat.

b) The time required for decontamination must be less than the remaining persistency of the contamination.

c) The unit may decontaminate only one-third of its current strength at a time in order to preserve its capability to defend itself.

Operational decontamination removes much of the gross contamination thereby limiting the spread of contamination across the battlefield. To be most effective, this type of decontamination should occur within one hour of contamination and as close to the contaminated area as possible [9: 1-2-4]. The rate of operational decontamination,

$Decon_{OpRate}$, is approximately 15 vehicles per hour [9: 3-2]. Thus, the time required to perform operational decontamination, $T_{DeconOp}$, is depicted:

$$T_{DeconOp} = (Cont_{(i)} * ES) / (Decon_{Resources} * Decon_{OpRate}) \qquad (35)$$

Equation (35) realistically assumes that decontamination operations begin immediately after contamination occurs and at the edge of the contaminated area. Also, all of the unit's decontamination resources are utilized and only the equipment contaminated from the chemical package encounter is decontaminated. Thus, Equation (35) is in accordance with the four principles of decontamination. The effectiveness of operational decontamination is specified by the user and reflected in the reduction of the weathering time or remaining persistency [9: 1-3]. Typically, operational decontamination will reduce in half the weathering of contamination. For example, if a unit conducts operational decontamination for 20 minutes on contamination with a persistency of 100 minutes, the result is contamination with only 40 minutes of remaining persistency.

Thorough decontamination reduces contamination to negligible risk levels thereby restoring a unit's combat power. Since thorough decontamination requires a large amount of resources and time, it is typically conducted upon completion of combat operations or during reconstitution [9: 1-5]. Also, it is generally supported with additional chemical unit assets. The rate of thorough decontamination, $Decon_{ThorRate}$, is approximately 3 vehicles per hour [9: 4-17]. The time required to perform thorough decontamination, $T_{DeconThor}$, is depicted:

$$T_{DeconThor} = (Cont_{Overall} * ES) / (Decon_{Resources} * Decon_{ThorRate}) \qquad (36)$$

Since thorough decontamination is resource intensive, it is only conducted upon the completion of a unit mission or activity or upon the unit conducting reconstitution. Reconstitution typically occurs when a unit falls below the withdrawal threshold established by the user [31: 24]. Also, the unit may utilize up to half of the decontamination resources of its parent unit if they are available. For example, a brigade may utilize up to half of the division's decontamination resources. In contrast to operational decontamination, thorough decontamination is performed on all contaminated equipment. The result of thorough decontamination is the removal of all contamination and restoration of combat power.

3.11 Updating Unit Full Protection and Contamination Status

The effects of a single encounter with a chemical package are determined using the equations presented in Sections 3.9.1-3 depending upon the method of encounter. In particular, these equations determine the fraction of unit contaminated ($Cont_{(i)}$) and the fraction of unit that must assume full protection ($FProt_{(i)}$) as well as their associated persistencies. Utilizing these values, the contamination and protection status of the overall unit are determined.

The overall full protection status of a unit is determined utilizing the fractions of unit assuming full protection from each chemical package encounter and is depicted:

$$FProt_{Overall} = 1 - \prod_{i \in I}^{I} \left(1 - FProt_{(i)}\right) \tag{37}$$

where

I = the set of chemical package encounters that have not expired

Equation (37) assumes that a proportional fraction of unit not in full protection prior to encounter (i) must assume full protection due to encounter (i).

Similarly, the overall contamination status of a unit is computed according to Equation (38).

$$\text{Cont}_{\text{Overall}} = 1 - \prod_{i \in I}^{I} \left(1 - \text{Cont}_{(i)}\right) \tag{38}$$

where

I = the set of chemical package encounters that have not expired

Equation (38) also assumes that a proportional fraction of unit contaminated prior to encounter (i) is contaminated due to encounter (i).

As the associated persistency or TIME expires for a particular contamination or full protection value, the overall unit status must be recalculated. This calculation is made utilizing the remaining values and continues until their associated periods of time have expired. In order to do so, JWAEP must maintain both a contamination and full protection status log. These logs contain the fractions of unit contamination and full protection and their associated persistencies for each chemical package encounter as well as the simulation time at which occur. Upon a change in weather conditions or completion of decontamination operations, the persistencies and simulation times are updated. Tables 18 and 19 on the following page depict an example of both types of unit status logs.

Table 18 Example of Unit Full Protection Log

Encounter	Chemical Package	Fraction of Unit	Persistency or TIME	Simulation Time	Overall Unit Status
1	P-VX	.3	200 minutes	1440 minutes	.3
2	NP-G	.6	20 minutes	1560 minutes	.72
				1580 minutes	.3
3	P-VX	.2	1000 minutes	1630 minutes	.44
				1640 minutes	.2
4	P-VX	.1	400 minutes	1700 minutes	.28

Table 19 Example of Unit Contamination Log

Encounter	Chemical Package	Fraction of Unit	Persistency	Simulation Time	Overall Unit Status
1	P-VX	.3	200 minutes	1440 minutes	.3
2	NP-G	0	N/A	1560 minutes	.3
3	P-VX	.2	1000 minutes	1630 minutes	.44
				1640 minutes	.2
4	P-VX	.1	400 minutes	1700 minutes	.28

An example of this calculation is provided using the examples in tables above and Equations (37) and (38). Assuming the unit's minimum level of protection is not full protection, the overall current unit status at simulation time 1439 minutes is:

$$FProt_{Overall} = 0$$

$$Cont_{Overall} = 0$$

At simulation time 1440 minutes, the unit encounters a persistent chemical package. The overall unit status is:

$$FProt_{Overall} = 1 - (1 - .3) = .3$$

$$Cont_{Overall} = 1 - (1 - .3) = .3$$

Since the encounter results from persistent contamination, the overall current unit status for both logs is equivalent.

At simulation time 1560 minutes, the unit encounters a non-persistent chemical package. The overall unit status is:

$FProt_{Overall} = 1 - (1 - .3) * (1 - .6) = .72$

$Cont_{Overall} = 1 - (1 - .3) * (1 - 0) = .3$

Since the encounter results from a non-persistent cloud, the unit does not receive any further contamination.

At simulation time 1580, the TIME associated with the non-persistent cloud encounter (2) expires and the overall unit status is recalculated.

$FProt_{Overall} = 1 - (1 - .3) = .3$

$Cont_{Overall} = 1 - (1 - .3) = .3$

At simulation time 1630, the unit encounters (3) a persistent chemical package. The overall unit status is:

$FProt_{Overall} = 1 - (1 - .3) * (1 - .2) = .44$

$Cont_{Overall} = 1 - (1 - .3) * (1 - .2) = .44$

At simulation time 1640, the persistency associated with the persistent chemical package encounter (1) expires and the overall unit status is recalculated.

$FProt_{Overall} = 1 - (1 - .2) = .2$

$Cont_{Overall} = 1 - (1 - .2) = .2$

At simulation time 1700, the unit encounters another persistent chemical package (4). The overall unit status is:

$FProt_{Overall} = 1 - (1 - .2) * (1 - .1) = .28$

$Cont_{Overall} = 1 - (1 - .2) * (1 - .1) = .28$

This process is continued for each chemical package encounter or expiration until the simulation is completed.

IV. RESULTS AND ANALYSIS

4.1 Scenario for Chemical Weapons Use Effects

A realistic JWAEP scenario of chemical weapons use applies the coverage, contamination, full protection, effectiveness, attrition, and negotiation and decontamination time equations developed in Chapter 3 so the chemical weapons effects can be analyzed. The scenario depicted in Table 21 illustrates the effects of chemical weapons use on an encountering unit and provides the mechanism for the testing and verification of these equations and parameter values. However, prior to determining the chemical weapons effects, several scenario parameters must be defined. These parameters include those associated with the unit, terrain and weather conditions, and chemical packages.

Unit Parameters:

Unit Type: Armored Brigade conducting a movement to contact along an arc
Length: 3000 meters
Width: 2000 meters
R_U: 1803 meters
$Unit_{Orient}$: 30 degrees
ES: 500 pieces of equipment
PS: 2000 personnel
Decon Resources: 4 for unit and 16 for parent unit
UMR in NProt: 10 KM/HR or 166.67 M/MIN
Perception Threshold: 0.7
L_{PProt}: 0.6 for persistent types and 0.7 for non-persistent types
L_{FProt}: 0.02 for both types
Eff_{PProt}: 0.9 for unopposed movement and 0.88 for movement to contact
Eff_{FProt}: 0.8 for unopposed movement and 0.72 for movement to contact

Terrain and Weather Parameters:

Terrain Type: Rough
Wind Speed Reduction Factor: 0.8
Wind Direction: 270 degrees
Global Wind Speed: 16 KM/HR or 266.67 M/MIN
Temperature: 70 degrees Fahrenheit
Air Stability: Stable

Chemical Package Attributes:

Table 20 Chemical Package Attributes for Scenario

Encounter	Package Type	R_C	DSD	L	P_t	CP	NP
#1	Persistent VX	600	0	.92	3000	3000	4000
#2	Non-Persistent GB	250	1500	.78	20	30	N/A
#3	Persistent HL	400	0	.86	4000	5000	N/A
#4	Persistent VX	900	0	.85	4000	6000	N/A

Scenario Events:

Table 21 Chemical Battlefield Scenario

Encounter	Method of Encounter	Tactic(s)	Decon Type	SimTime
#1	Employment (d=1300)	N/A	Operational	500
#2	Discovery	Bull-through	N/A	700
Temperature Change to New Class (TC)				800
#3	Perception Threshold	Recon/Survey/Bypass	N/A	1000
#4	Discovery	Bull-through	Operational	1200
Mission Complete (MC)			Thorough	1600

Since the adjusted penetration distance, $Dist_{Adj\ Pen}$, is determined with a random draw from a uniform distribution, this parameter was assigned values of 205 meters and 120 meters for encounters (2) and (4), respectively.

4.2 Results Due to Encountering Chemical Packages

The following sections illustrate the algorithm results for determining the effects due to encountering the chemical packages depicted in the scenario in Table 21. These results are produced from the methodologies, procedures, and equations identified and discussed in Chapter 3.

4.2.1 Unit Coverage, Contamination, and Full Protection Results

Using the equations from the methodology section, the fractions of unit coverage (Cov), contamination (Cont), and assuming full protection (FProt) due to each encounter are determined from the data parameters defined in the scenario and depicted in Table 22.

Cov: Equations (6-8), (26), and (28)
Cont: Equation (12)
FProt: Equations (13) and (19)

Table 22 Coverage, Contamination, and Full Protection Results for Scenario

Encounter	Cov	Cont	FProt	SimTime
#1	.106	.106	.106	500
#2	.0162	N/A	.25	700
#3	N/A	N/A	N/A	1000
#4	.6	.6	.6	1200

4.2.2 Attrition Results

The attrition effects from encountering chemical packages consist of losses within the initial coverage area upon employment or discovery and losses within the downwind hazard area, if applicable. The attrition results for the scenario are computed according to the following equations and depicted in Table 23:

$Attr_{DL}$: Equation (10)
$Attr_{DWH}$: Equation (11)
$Attr_{Employ}$: Equation (9)
$Attr_{Discovery}$: Equation (27)
$Attr_{Bull}$: Equation (29)

Table 23 Attrition Results for Scenario

Encounter	$Attr_{DL}$	$Attr_{DWH}$	$Attr_{Employ}$	$Attr_{Discovery}$	$Attr_{Bull}$	Total
#1	116.72	N/A	116.72	N/A	N/A	116.72
#2	14.91	4.04	N/A	18.95	N/A	18.95
#3	N/A	N/A	N/A	N/A	N/A	0
#4	18.26	N/A	N/A	18.26	18.34	36.6
Total	149.89	4.04	116.72	37.21	18.34	172.27

The total attrition for the scenario is 172.27 personnel.

4.2.3 Chemical Hazard Negotiation Time Results

The time required to negotiate chemical hazards is a function of the type and size of the chemical package, the current perception of chemical package existence, and the unit tactic(s) employed by the encountering unit. The results portraying the time required to negotiate the chemical hazards for the scenario are computed according to the following equations and depicted in Table 24:

T_{Sur}: Equation (30)
T_{By}: Equation (32)
T_{Bull}: Equations (33-34)

Table 24 Chemical Package Negotiation Time Results for Scenario

Encounter	T_{Dis}	T_R	T_{Sur}	T_{By}	T_{Bull}	Total
#1	N/A	N/A	N/A	N/A	N/A	0
#2	N/A	N/A	N/A	N/A	8.65	8.65
#3	N/A	30	52.0	8.1	N/A	90.1
#4	10	N/A	N/A	N/A	27.28	37.28
Total	10	30	52.0	8.1	35.93	136.03

The total time required to negotiate the chemical hazards for the scenario is 136.03 minutes.

4.2.4 Decontamination Time Results

The time required to conduct decontamination operations is a function of the type of decontamination performed, the fraction of unit requiring decontamination, and the number of decontamination resources used. The decontamination times for the scenario are computed utilizing the following equations and depicted in Table 25:

$T_{DeconOp}$: Equation (35)
$T_{DeconThor}$: Equation (36)

Table 25 Decontamination Time Results for Scenario

Encounter	$T_{Decon} < P_t$	$T_{DeconOp}$	$T_{DeconThor}$	Total
#1	Yes	52.86	N/A	52.86
#2	N/A	N/A	N/A	0
#3	N/A	N/A	N/A	0
#4	Yes	300	N/A	300
MC	Yes	N/A	535.24	535.24
Total		352.86	535.24	888.1

The total time to perform decontamination operations for the scenario is 888.1 minutes or 14.8 hours. At the completion of thorough decontamination, the unit returns to partial protection and full effectiveness at its current state.

4.2.5 Overall Unit Status and Effectiveness Results

The overall unit status and effectiveness for the scenario are computed according to the following equations and are depicted in Table 26 on the following page:

$FProt_{Overall}$: Equation (37)
$Cont_{Overall}$: Equation (38)
$Eff_{Overall}$: Equation (1)

Table 26 Overall Unit Status and Effectiveness Results for Scenario

	Encounter		Status		Effectiveness			After Decon	
Encounter	FProt	Cont	FProt	Cont	Unopp Move	UMR	Move to Contact	P_t or TIME	Sim Time
#1	.106	.106	.106	.106	.8894	148.2	.8631	1473.6	552.9
#2	.25	0	.329	.106	.8671	144.5	.8273	N/A	N/A
Temperature Change									
#1	.106	.106	.106	.106	.8894	148.2	.8631	1635.2	800
#2	Expired								
#3	0	0	.106	.106	.8894	148.2	.8631	N/A	1000
#4	.6	.6	.642	.642	.8358	139.3	.7772	1831.4	1537.3
MC	0	0	0	0	1	166.7	1	0	2135.2

Table 26 also depicts the remaining persistency of unit contamination after decontamination operations have been performed. The overall effectiveness represents the effectiveness of the unit in its current state and is applied after all other factors have been considered.

4.3 Unit Tactics Decision Results

The doctrinal unit tactics established for units encountering or perceiving chemical packages in JWAEP are chemical reconnaissance and survey, bypass, and bull-through. Under nonclose combat conditions, units will conduct chemical reconnaissance at a location if the perception threshold is reached and the largest perceived threat is persistent chemical packages. A persistent chemical package in JWAEP will always be bypassed unless the package is situated in natural terrain such that a bypass route is untenable. Therefore, upon discovering or confirming the presence of persistent chemical packages, units conduct a chemical survey to determine the feasibility of bypassing. If bypassing is impossible, the unit conducts a bull-through operation. The effects of these unit tactics are developed in sections 3.8-10 of this document.

In analyzing the tactical decision process, it is apparent that persistent chemical packages employed in nonclose combat conditions will probably be bypassed upon discovery or chemical reconnaissance confirmation. Although the time required to bull-through these packages may be less than the time required to conduct survey and bypass operations, the decontamination times associated with bulling-through contamination clearly indicate that bypassing is the preferred unit tactic. Also, the unit does not incur further degradation in its overall effectiveness. Table 27 compares the scenario results for encounters 3 and 4 and clearly indicates the advantage of bypass operations. Although the time required to negotiate encounter #3 is greater than that of encounter #4, the decontamination requirements resulting from encounter #4 significantly increase the total time associated with the encounter. Likewise, the overall unit effectiveness remains unaffected from encounter #3 while decreasing significantly due to encounter #4. Thus, the doctrinal rules identified in Table 17 of Chapter 3 are valid for nonclose combat conditions in JWAEP.

Table 27 Comparison of Scenario Unit Tactics

	Time		Effectiveness	
Encounter #	Negotiation	Decon	Unopp. Movement	Move to Contact
3 (Bypass)	90.1	0	.8894	.8631
4 (Bull)	37.28	300	.8358	.7772

The chemical packages, once discovered and negotiated, are *flagged* so that follow-on forces do not receive discovery effects and do not have to perform chemical reconnaissance or survey operations. The chemical packages remain on the JWAEP battlefield until their persistency has expired.

4.4 Verification of Results

Verification of the scenario results requires an analysis of the algorithms and their results. The analysis involves the testing of the algorithms by varying parameters to determine if the results logically change according to the changes in the parameters. The algorithms requiring verification include coverage, full protection, attrition, negotiation time, decontamination time, and effectiveness. However, since the effects of chemical weapons use are dependent on numerous parameters which are used in similar manners by the algorithms, only a representative sample of effects from the scenario were chosen for the verification process. Table 28 reflects the verification process for the representative samples and the following example illustrates the conduct of this verification.

Verification of the fraction of unit coverage from the initial dispersion of chemical packages is accomplished by varying the distance between the aim point and the center mass location of the unit, assuming that the current distance does not correspond to total overlap. As the distance increases, the fraction of unit coverage is expected to decrease. Using the scenario and the results for encounter #1:

Encounter #1 (Persistent - VX)

R_U = 1803 meters

R_C = 600 meters

d = 1300 meters

$Cov_{(1)}$ = .106

$Attr_{Employ}$ = 116.72 personnel losses

Using the same conditions for encounter #1 and decreasing the distance to analyze the effect on unit coverage yields:

$$d = 1000 \text{ meters}$$
$$Cov_{(1)} = .111$$

Similarly, as the fraction of unit coverage increases, the number of personnel losses are also expected to increase. Therefore, the verification of attrition due to employment effects may also be accomplished. Using the increased coverage determined above to analyze the effect on attrition yields:

$$Attr_{Employ\,(1)} = 122.544 \text{ personnel losses}$$

As expected, both fraction of unit coverage and attrition do increase as the distance between the aim point and unit center mass location decreases. Thus, the fraction of unit coverage and attrition algorithms due to employment of chemical weapons are yielding results consistent with expected results.

Table 28 on the following page reflects the verification effort for the representative samples and incorporates fluctuations of input parameters in each of the algorithms. The results indicate that the algorithms produce expected results based upon the parameter fluctuation. Similarly, verification of the chemical package perception generating process was achieved in the example provided in Section 3.7. Thus, the algorithms presented in Chapter 3 for representing the effects of chemical weapons use yield verifiable and consistent results. These results will be analyzed for sensitivity of parameters in the subsequent section.

Table 28 Verification of Methodologies

Encounter Number	Algorithm(s)	Parameter	Parameter Variation Direction	Expected Result Direction	Actual Result	Actual Result Direction	Verified
1	Cov	d	Increase	Decrease	.097	Decrease	Yes
	Cov	d	Decrease	Increase	.111	Increase	Yes
2	Cov	Width	Increase	Decrease	.0125	Decrease	Yes
	Cov	Width	Decrease	Increase	.0317	Increase	Yes
	Cov	Length	Increase	Decrease	.0135	Decrease	Yes
	Cov	Length	Decrease	Increase	.02	Increase	Yes
	Cov	R_C	Increase	Increase	.0222	Increase	Yes
	Cov	R_C	Decrease	Decrease	.0135	Decrease	Yes
4	Cov	Length	Increase	Decrease	.45	Decrease	Yes
	Cov	Length	Decrease	Increase	.9	Increase	Yes
	Cov	R_C	Increase	Increase	.8	Increase	Yes
	Cov	R_C	Decrease	Decrease	.333	Decrease	Yes
2	FProt	Length	Increase	No Change	.25	No Change	Yes
	FProt	Length	Decrease	No Change	.25	No Change	Yes
	FProt	Width	Increase	Decrease	.227	Decrease	Yes
	FProt	Width	Decrease	Increase	.278	Increase	Yes
1	$Attr_{Employ}$	L	Increase	Increase	125.6	Increase	Yes
	$Attr_{Employ}$	L	Decrease	Decrease	107.8	Decrease	Yes
	$Attr_{Employ}$	L_{PProt}	Increase	Increase	155.6	Increase	Yes
	$Attr_{Employ}$	L_{PProt}	Decrease	Decrease	77.8	Decrease	Yes
	$Attr_{Employ}$	Cov	Increase	Increase	149.2	Increase	Yes
	$Attr_{Employ}$	Cov	Decrease	Decrease	54.3	Decrease	Yes
2	$Attr_{Discovery}$	SCALE	Increase	Increase	19.5	Increase	Yes
	$Attr_{Discovery}$	SCALE	Decrease	Decrease	17.8	Decrease	Yes
2	Neg. Time	R_C	Increase	Increase	9.04	Increase	Yes
	Neg. Time	R_C	Decrease	Decrease	8.26	Decrease	Yes
	Neg. Time	DSD	Increase	No Change	8.65	No Change	Yes
	Neg. Time	DSD	Decrease	No Change	8.65	No Change	Yes
3	Neg. Time	R_C	Increase	Increase	120.1	Increase	Yes
	Neg. Time	R_C	Decrease	Decrease	60.1	Decrease	Yes
	Neg. Time	T_{Sam}	Increase	Increase	106.1	Increase	Yes
	Neg. Time	T_{Sam}	Decrease	Decrease	74.1	Decrease	Yes
	Neg. Time	D_{BS}	Increase	Decrease	76.8	Decrease	Yes
	Neg. Time	D_{BS}	Decrease	Increase	130.1	Increase	Yes
4	Neg. Time	UMR	Increase	Decrease	26.76	Decrease	Yes
	Neg. Time	UMR	Decrease	Increase	28.15	Increase	Yes
1	$Decon_{Opn}$	$Decon_{Resources}$	Increase	Decrease	30.2	Decrease	Yes
	$Decon_{Opn}$	$Decon_{Resources}$	Decrease	Increase	211.4	Increase	Yes
	$Decon_{Opn}$	$Decon_{OpRate}$	Increase	Decrease	44.1	Decrease	Yes
	$Decon_{Opn}$	$Decon_{OpRate}$	Decrease	Increase	66.1	Increase	Yes
MC	$Decon_{Thor}$	$Decon_{Resources}$	Increase	Decrease	428.2	Decrease	Yes
	$Decon_{Thor}$	$Decon_{Resources}$	Decrease	Increase	713.7	Increase	Yes
	$Decon_{Thor}$	$Decon_{ThorRate}$	Increase	Decrease	401.4	Decrease	Yes
	$Decon_{Thor}$	$Decon_{ThorRate}$	Decrease	Increase	802.9	Increase	Yes
1	$Eff_{Overall}$	Eff_{PProt}	Increase	Increase	.934	Increase	Yes
	$Eff_{Overall}$	Eff_{PProt}	Decrease	Decrease	.845	Decrease	Yes

4.5 Sensitivity Analysis of Results

Using the scenario depicted in Table 21, the methodologies proposed in Chapter 3 for representing the effects of chemical weapons use were verified by realistically varying input parameters and analyzing the algorithm outputs. The output analysis indicates that the algorithms yield verifiable effects.

In analyzing the attrition results, it is apparent that conducting a bypass operation when encountering persistent chemical packages will produce significantly less personnel losses as compared to bulling-through the same package. Also, the number of initial dispersion or discovery losses from both types of packages decreases as the fraction of unit in full protection prior to the encounter increases. The amount of decrease is dependent upon the lethality reduction factors for unit protective levels and the lethality of the chemical package. However, if a unit encounters the same chemical package prototype twice and has a larger fraction of unit in full protection prior to the second encounter than the first, the amount of decrease will be proportional to the amount increase in full protection times the difference between lethality protection factors. The attrition effect within the downwind hazard area is unaffected by the prior overall unit status in full protection since the fraction of unit within the area assumes full protection upon an encounter.

As discussed in Section 4.3, an analysis of unit tactics and their associated times supports the doctrinal requirement of bypassing persistent chemical packages upon their encounter under nonclose conditions. The perception threshold must be carefully defined by the user based upon the amount of acceptable risk. A significantly low perception threshold may result in numerous unneeded chemical reconnaissance missions while a high perception threshold may increase the number of discovery encounters, thereby resulting in additional attrition, contamination, degradation, and time effects.

An analysis of unit decontamination operations determined that the time required to conduct decontamination is significantly sensitive to the number of decontamination resources used. This is especially evident for thorough decontamination. Supposing that the number of parent unit decontamination resources is reduced to eight, the time required to perform thorough decontamination upon mission completion (MC) increases by 267.7 minutes to 802.9 minutes. This result shows the value of decontamination assets on the battlefield and emphasizes the appropriate task organization for combat. Further analysis also determined the requirement for an additional rule for decontamination operations. The typical chemical protective clothing worn by the U.S. military is the Battledress Overgarment (BDO). The BDO may be worn for up to 30 days, however, it must be exchanged within 24 hours after exposure to liquid contamination [10: 1-1]. The current decontamination rules allow units to exceed this period without performing subsequent decontamination operations. Therefore, the following rule must be added to the existing set of rules in the model for decontamination operations listed in Section 3.10.2:

d) The unit must conduct thorough decontamination within 24 hours after operational decontamination if the time required for decontamination is still less than the remaining persistency of the contamination.

The addition of this rule forces a unit to perform thorough decontamination within a reasonable period of time after encountering contamination. Otherwise, a contaminated unit may possibly never undergo thorough decontamination even though the remaining persistency of the contamination is extremely large.

Model validation begins by developing a model with high face validity, from which outputs seem reasonable to experts of the system being modeled [19: 338-9]. Using this approach, the scenario and algorithmic results were presented to three chemical warfare experts at the U.S. Army Chemical School Modeling and Analysis Branch for initial validation. Each of these experts reviewed the algorithms and results and confirmed that they were indeed reasonable. Specifically, they stated the following [20]:

- The fraction of unit that assumes full protection due to an encounter with a chemical package accurately reflects both the chemical hazard threat and current joint doctrine.
- The attrition resulting from encounters with chemical packages realistically captures both the initial discovery or employment losses as well as losses resulting from protective equipment failure. Also, casualties resulting from bursting munitions are insignificant and do not require modeling since most delivery munitions are air bursting.
- The unit tactical decision process realistically portrays a commander's decision making process based upon the type of chemical package threat. Likewise, the times required to negotiate the chemical packages are also reasonable.
- Decontamination rules and times are doctrinally based and capture the adverse effects of persistent chemical package encounters.

- The determination of unit effectiveness for specific activities provides an adequate representation of degradation resulting from levels of protection. However, a more realistic representation should be explored as discussed in Section 5.4.

Also, the scenario and algorithmic results passed the author's common sense check based on his education, training, and 9 years of experience as a chemical officer.

The next step in the validation process is to establish that the model output data closely resembles the output data that would be expected from the actual system [19: 340-1]. Typically, this type of validation is performed by comparing the proposed model output to an existing validated model's output. However, there exists no current model that determines the effects of chemical weapon's use in a similar manner. Therefore, further validation efforts are required upon implementation of this research into JWAEP.

In summary, the results obtained from the methodology and algorithms presented in Chapter 3 are consistent and comparable with the chemical modeling experts results and the author's common sense results. An analysis of the algorithms results identified a minor discrepancy in the decontamination rules, the proper unit tactic(s) when encountering or perceiving chemical packages, and the need for potential follow-on work. The recommendations section in Chapter 5 identifies decision rules for both unit tactics and decontamination operations and further discusses the required follow-on work.

V. RECOMMENDATIONS AND CONCLUSIONS

5.1 Summary

Chapter 3 developed the methodology to accurately model chemical weapons use and the resulting effects in the JWAEP model. The final representation incorporated high resolution effects within the low resolution JWAEP using Army doctrine and existing concepts from other combat models. This representation included:

a) The identification of required parameters to be included in the development of a future weather module and their effects on chemical weapons use.

b) The structure representation of chemical packages on the battlefield.

c) Fitting the chemical package intelligence acquisition process for perception of potential enemy chemical weapons use into the existing JWAEP intelligence architecture.

d) Algorithms which use existing doctrine to represent chemical weapons effects:

1) Coverage
2) Contamination
3) Levels of protection
4) Attrition
5) Time
6) Degradation

e) A doctrinally based representation of various unit tactics under nonclose combat conditions in JWAEP which reflects the best defense against enemy use of chemical weapons: contamination avoidance [8: vi].

The chemical weapons scenario and algorithmic results depicted in Chapter 4 verify the proposed methodology and solution techniques. The reasonableness of the modeled effects were partially validated by expert opinion. Together, the verification and validation efforts allow several key conclusions to be drawn.

5.2 Conclusions

1) The proposed methodology and solution techniques provide doctrinally based effects to explicitly model chemical weapons use and the resulting effects in JWAEP.

2) The chemical package intelligence acquisition process effectively links with the existing JWAEP intelligence architecture to represent the uncertainty of a chemical battlefield.

3) The algorithms for the various effects doctrinally quantify these effects upon encountering or perceiving chemical packages.

4) The unit tactical decision process incorporated into JWAEP explicitly represents current doctrine for negotiating chemical hazards.

5.3 Recommendations

The following recommendations should allow this methodology to be implemented into the JWAEP model.

1) Linking the Chemical Package Intelligence Acquisition Process.

The current JWAEP architecture is structured to generate a perception of enemy units. Since a chemical package is represented as an "enemy unit", the linking of the chemical package intelligence acquisition process into the current intelligence structure is significantly simplified. The attributes for a chemical package are similar in nature and architecture to the attributes of enemy units, thereby further simplifying the linking process

[29]. However, the sensor parameters need to be established in JWAEP so that intelligence on chemical package existence feeds the Bayesian process for comparison against similar chemical package prototypes to develop a perception of a chemical package's existence, size, type, and location.

2) Linking the Unit Tactical Decision Process.

The employment of various unit tactics upon encountering or perceiving chemical packages during nonclose combat conditions is modeled in JWAEP using a decision rule set based on doctrine. Incorporating these decision rules into JWAEP involves a linkage to the existing JWAEP architecture.

The decision rules depicted in Table 17 on page 83 need to be incorporated into the JWAEP command, control, communications and intelligence (C3I) process to ensure doctrinally correct tactics under nonclose conditions. Also, the following set of rules governs the conduct of decontamination operations.

a) The unit is not engaged in close combat.

b) The time required for decontamination must be less than the remaining persistency of the contamination.

c) The unit may decontaminate only one-third of its current strength at a time in order to preserve its capability to defend itself.

d) The unit must conduct thorough decontamination within 24 hours after operational decontamination if the time required for decontamination is still less than the remaining persistency of the contamination.

Although this rule set does not permit a contaminated unit to continue operations in excess of a 24 hour period, this representation is doctrinally realistic and valid. A unit seeks to rapidly restore its combat power during nonclose combat conditions in preparation for possible future close combat. Therefore, it is highly unlikely that a unit will continue to operate in a contaminated state for longer than this period.

3) Chemical Effects Support Tool.

The methodology and techniques described in this thesis can also be used by the U.S. Army Chemical School to support instruction on the effects of chemical weapons use on the battlefield. Currently, there exists no quick-turn tool to quantify and demonstrate these effects to students. For example, students can observe such effects as unit attrition, degradation and decontamination due to encountering chemical packages and utilize the results during several wargaming exercises.

5.4 Follow-On Work

As discussed in Section 3.4.3, unit degradation will most likely increase as the length of time a unit remains in an elevated level of protection increases. Therefore, a more realistic representation of degradation of unit effectiveness may be achieved by determining the overall effectiveness of a unit based upon the length of time the affected fraction of unit from encounter (i) has been in the protective level. This length of time may be decomposed into distinct time periods over which the degradation would remain constant. For example, one time period may represent a 6 hour period. Thus, any portion of unit remaining in an elevated protective level longer than this period would experience a greater amount of degradation than would occur in the initial 6 hour period. However, the rate of degradation over successive time periods is left for further efforts and must be determined in coordination with the U.S. Army Chemical School. Also, the application of the overall unit effectiveness for adjudication of close combat using the Attrition Calibration (ATCAL) model must be developed.

Due to JWAEP's current lack of logistics representation, the effect of chemical weapons use on the battlefield and its impact on logistical functions was not developed. However, this impact can be quite significant if widespread chemical weapons use occurs. In this environment, the consumption of supplies increases significantly. Additionally, decontamination operations require significant amounts of water and decontamination materials. Thus, upon the implementation of a logistical network, the logistical constraints imposed on model functions by encountering chemical packages should be developed.

The last follow-on work recommendation proposes the incorporation of the perception of chemical package existence into the automatic path generation process for unit movement. This process utilizes a modified Dykstra total cost algorithm which is weighted by perceived attrition and delay [17: 70-73, 31: 34] to determine the least cost arc to travel. In a similar manner, the Dykstra algorithm may be further modified to include the perception of chemical package existence. This modification may include perceived attrition and delay based upon the perceived attributes of a chemical packages located on an arc.

APPENDIX A: Chemical Unit Organization

This appendix lists the chemical unit organizations and their basis of allocation, mission statement, and TOE equipment.

Section I
Command and Control Elements

Chemical Unit	Normal Assignment	Normal Basis of Allocation	Mission Statement	Equipment
HHD, Chemical Brigade	To Corps	1 per Corps	To provide command and control for two to six chemical battalions.	
HHD, Chemical Battalion	To Corps/ TAACOM	1 per 2-5 chemical companies	To provide command and control for 2-5 chemical companies.	
HHD, Chemical Battalion (Enhanced, Theater Army)	To TAACOM	1 per 3-7 chemical companies	To provide command and control for 3-7 chemical companies.	

Section II
Chemical Companies

Chemical Company (Smoke/Decon)	Organic to Airborne Division	1 per Airborne Division	To provide equipment decon, large area smoke, NBC warning and reporting, and chemical staff support for an Airborne Division.	18 - M17 LDS

Chemical Unit	Normal Assignment	Normal Basis of Allocation	Mission Statement	Equipment
Chemical Company (Smoke/Decon)	Organic to Air Assault Division	1 per Air Assault Division	To provide equipment decon, large area smoke, NBC warning and reporting, and chemical staff support for an Air Assault Division.	18 - M17 LDS
Chemical Company (Heavy Division)	Organic to Heavy Division	1 per Mechanized or Armored Division	To provide equipment decon, large area smoke, NBC reconnaissance, NBC warning and reporting, and chemical staff support to a heavy division.	12 - M12A1 PDDA 6 - M93 FOX
Chemical Company (Smoke/Decon/ Reconnaissance)	Organic to Armored Cavalry Regiment (ACR)	1 per ACR	To provide equipment decon, large area smoke, NBC reconnaissance, NBC warning and reporting, and chemical staff support to an ACR.	3 - M17 LDS
Chemical Company (Decon) (Corps/TA)	To Corps/ TAACOM	2 per corps (NATO). 1 per corps (SWA) 2 per TAACOM 1 per heavy division (NATO) 1 per division (SWA)	To provide decontamination support for elements of a corps/theater army	15 - M12A1 PDDA

Chemical Unit	Normal Assignment	Normal Basis of Allocation	Mission Statement	Equipment
Chemical Company (Smoke/Decon) (Corps)	To Corps	1 per light division	To provide equipment decon and large area smoke support for a light division.	24 - M17 LDS
Chemical Company (Smoke/Decon) (Corps/TA)	To Corps	1 per light division 1 per heavy division 6 per corps	To provide equipment decon and large area smoke support for elements of a corps/theater army.	24 - M17 LDS
Chemical Company (Recon)	To Corps/ TAACOM	1 per TA and corps	To provide NBC reconnaissance support for elements of a corps/theater army.	22 - M21 36 - M93 FOX

Section III
Chemical Teams

LA Team (Recon)	To a separate brigade and theater defense brigade	1 per separate brigade 1 per theater defense brigade	To provide NBC reconnaissance support.	3 - M8A1 1 - CAM
LB Team (Recon - SF)	To a Special Forces Group	1 per Special Forces Group	To provide NBC reconnaissance support.	1 - M8A1 1 - CAM

APPENDIX B: U.S. Army Chemical Equipment

1. Decontamination Equipment:

M17 Lightweight Decontamination System (LDS) [6: A-III-1]

The M17 LDS consists of a pumper/heating unit and a 1,580 gallon water storage tank. It is a portable, compact gasoline-powered 2-stroke engine, with a belt-driven water pump and coil-type water heating unit. The M17 is capable of drawing water from 30 feet away and 9 feet below pump level and deliver it at controlled temperatures up to 120 degree Celsius and pressure up to 100 pounds per square inch. The entire unit is independent of outside power. Heavy units contain an organic M17 LDS and chemical decontamination units posses the M17 LDS with a standard issue of 6 per platoon.

M12A1 Power-Driven Decontamination Apparatus (PDDA) [6: AIII-0]

The M12A1 PDDA consists of a pump unit, a 500 gallon water tank, and M2 water heater. The pump unit delivers up to 50 gallons of water per minute at a working pressure of approximately 105 pounds per square inch. The heater is capable of heating water to a temperature of 100 degrees Fahrenheit at a rate of 600 gallons per hour. Chemical decontamination units possess the M12A1 PDDA with a standard issue of 3 per platoon.

2. Chemical Agent Detection Equipment:

Automatic Chemical Agent Alarms [8: 3-1-2]

The M8 and M8A1 series alarms detect nerve agent vapor. Typically, stationary units position the alarms upwind of their position to decrease the chance of a surprise encounter by a non-persistent chemical cloud. However, the M8A1 alarm may be vehicle mounted. These alarms detect the following types of agents: G and V series nerve agent. The alarms operate in a temperature range of -40 degrees to 120 degrees Fahrenheit. All units possess these alarms.

Chemical Agent Monitor (CAM) [8: 3-2-3]

The CAM is a point monitor which can report vapor conditions at the front of the nozzle assembly. It cannot give a realistic assessment of vapor hazard over an area from one position and is typically used during decontamination operations to ensure contamination levels are negligible. The CAM detects both G and V series nerve agents as well as H series blister agents. All units posses this monitor.

ABC-M8 Chemical Agent Detector Paper [8: 3-4-5]

ABC-M8 Chemical Agent Detector Paper detects liquid chemical agents. Every soldier carries a booklet of detector paper. The detector paper detects both G and V series nerve agents as well as blister agents.

M9 Chemical Agent Detector Paper [8: 3-5]

M9 Chemical Agent Detector Paper is the most widely used method of detecting liquid chemical agents. Typically, the M9 paper is attached to personnel and equipment in readily observable locations. It is especially useful in detecting on-target attacks and keeping units from entering contaminated areas.

M256 Series Chemical Agent Detector Kit [8: 3-5]

The M256 kit is capable of detecting both liquid and vapor concentrations of chemical agents and is used primarily to determine the type of chemical agents present. It may detect the following chemical agents: G and V series nerve agents, H series blister agents, and blood agents. The standard issue of the M256 kit is at squad level.

M93 (FOX) NBC Reconnaissance System [8: 3-6]

The FOX is a fully integrated NBC reconnaissance system capable of locating, marking and reporting chemical agent contamination on the battlefield. It is capable of detecting all known chemical agents and monitoring twenty-two agents at any one time. The crew may obtain samples as well as mark contaminated areas without dismounting the vehicle. The vehicle may travel at speeds of 65 miles per hour and is capable of river crossing operations without additional preparation. Chemical reconnaissance units posses the M93 FOX with a standard issue of 6 per platoon.

M21 Remote Sensing Chemical Agent Alarm [8: 3-6-7]

The M21 is a passive infrared spectroradiometer that detects and identifies agent clouds within its line of sight. It operates by viewing the spectral characteristics of the chemical cloud comparing them to stored information of known agents. The stationary sensor scans a 60 degree horizontal arc every 60 seconds and can provide an azimuth direction to the cloud and its horizontal movement. It may operate within a temperature range of -25 degrees to 120 degrees Fahrenheit and is severely degraded by precipitation and strong winds. The M21 may detect G series nerve agents at a range up to 5 kilometers with an 85 percent probability of detection. The sensor will not detect vapor off-gassing from an area contaminated with persistent agents.

APPENDIX C: Sample Chemical Package Prototypes

The U.S. Army Chemical School will provide actual classified chemical package prototype parameters prior to conducting any analysis utilizing JWAEP, however, a set of reasonable unclassified data is provided. The source for this data is the TACWAR model [20, 26].

1. CHEMICAL PACKAGE TYPE: GB - Artillery

SIDE	TYPE	LETHALITY	DELIVERY.SYSTEM	ROUNDS.REQUIRED
2	NP	0.7	152mm	6

RADIUS(KM).AND.DOWNWIND.STRETCH.DISTANCE(KM).AND.PERSISTENCY (MIN).BY.WIND.AIR.STAB.CAT.BY.TEMPERATURE.CAT

	TEMPERATURE.CATEGORY					
WIND.AIR.STAB.CAT	1	2	3	4	5	6
1	.15 1.6 125	.15 1.8 50	.15 1.9 20	.15 2.0 10	.15 2.1 5	.15 2.2 1
2	.08 .6 120	.08 .6 45	.08 .6 21	.08 .7 10	.08 .7 5	.08 .7 1
3	.07 .5 115	.07 .5 45	.07 .5 20	.07 .5 10	.07 .5 5	.07 .5 1

END.RADIUS(KM).AND.DOWNWIND.STRETCH.DISTANCE(KM).AND. PERSISTENCY(MIN).BY.WIND.AIR.STAB.CAT.BY.TEMPERATURE.CAT

2. CHEMICAL PACKAGE TYPE: GB - Bomb

SIDE	TYPE	LETHALITY	DELIVERY.SYSTEM	ROUNDS.REQUIRED
2	NP	0.5	AIRCRAFT (Bomb)	1

RADIUS(KM).AND.DOWNWIND.STRETCH.DISTANCE(KM).AND.PERSISTENCY (MIN).BY.WIND.AIR.STAB.CAT.BY.TEMPERATURE.CAT

	TEMPERATURE.CATEGORY					
WIND.AIR.STAB.CAT	1	2	3	4	5	6
1	.94 50 850	.94 53 340	.94 56 145	.94 59 65	.94 62 30	.94 65 15
2	.95 8 810	.95 8 325	.95 9 145	.95 9 65	.95 10 30	.95 10 15
3	.91 3 745	.91 4 310	.91 4 135	.91 4 65	.91 4 30	.91 5 15

END.RADIUS(KM).AND.DOWNWIND.STRETCH.DISTANCE(KM).AND. PERSISTENCY(MIN).BY.WIND.AIR.STAB.CAT.BY.TEMPERATURE.CAT

3. CHEMICAL PACKAGE TYPE: GB - Missile

SIDE....TYPE....LETHALITY....DELIVERY.SYSTEM....ROUNDS.REQUIRED

SIDE	TYPE	LETHALITY	DELIVERY.SYSTEM	ROUNDS.REQUIRED
2	NP	0.92	SCUD	1

RADIUS(KM).AND.DOWNWIND.STRETCH.DISTANCE(KM).AND.PERSISTENCY (MIN).BY.WIND.AIR.STAB.CAT.BY.TEMPERATURE.CAT

TEMPERATURE.CATEGORY

WIND.AIR.STAB.CAT	1	2	3	4	5	6
1	.88 141 690	.53 22 310	.19 4 125	.08 2 45	.02 1 5	.01 .01 .01
2	.35 213 520	.17 9 195	.06 6 70	.04 4 15	.01 .01 .01	.01 .01 .01
3	.21 316 315	.14 12 110	.11 9 35	.02 6 5	.01 .01 .01	.01 .01 .01

END.RADIUS(KM).AND.DOWNWIND.STRETCH.DISTANCE(KM).AND. PERSISTENCY(MIN).BY.WIND.AIR.STAB.CAT.BY.TEMPERATURE.CAT

4. CHEMICAL PACKAGE TYPE: VX - Artillery

SIDE....TYPE....LETHALITY....DELIVERY.SYSTEM....ROUNDS.REQUIRED

SIDE	TYPE	LETHALITY	DELIVERY.SYSTEM	ROUNDS.REQUIRED
2	P	0.667	152mm	6

RADIUS(KM).AND.DOWNWIND.STRETCH.DISTANCE(KM).AND.PERSISTENCY (MIN).BY.WIND.AIR.STAB.CAT.BY.TEMPERATURE.CAT

TEMPERATURE.CATEGORY

WIND.AIR. STAB.CAT	1	2	3	4	5	6
1	.02 0 1400000	.02 0 60000	.02 0 12000	.02 0 2000	.02 0 700	.06 0 200
2	.01 0 2400000	.01 0 60000	.01 0 11000	.02 0 2000	.02 0 700	.02 0 200
3	.01 0 3300000	.01 0 60000	.01 0 11000	.02 0 2000	.02 0 600	.02 0 200

END.RADIUS(KM).AND.DOWNWIND.STRETCH.DISTANCE(KM).AND. PERSISTENCY(MIN).BY.WIND.AIR.STAB.CAT.BY.TEMPERATURE.CAT

5. CHEMICAL PACKAGE TYPE: VX - Bomb

SIDE....TYPE....LETHALITY....DELIVERY.SYSTEM....ROUNDS.REQUIRED

SIDE	TYPE	LETHALITY	DELIVERY.SYSTEM	ROUNDS.REQUIRED
2	P	0.405	AIRCRAFT (Bomb)	1

RADIUS(KM).AND.DOWNWIND.STRETCH.DISTANCE(KM).AND.PERSISTENCY (MIN).BY.WIND.AIR.STAB.CAT.BY.TEMPERATURE.CAT

WIND.AIR. TEMPERATURE.CATEGORY

STAB.CAT	1	2	3	4	5	6
1	.7 0 2000000	.3 0 300000	.4 0 50000	.4 0 13000	.5 0 4000	.4 0 1000
2	.05 0 3000000	.2 0 400000	.2 0 80000	.2 0 17000	.1 0 5000	.2 0 1000
3	.02 0 4000000	.02 0 400000	.1 0 80000	.2 0 19000	.1 0 5000	.2 0 1000

END.RADIUS(KM).AND.DOWNWIND.STRETCH.DISTANCE(KM).AND. PERSISTENCY(MIN).BY.WIND.AIR.STAB.CAT.BY.TEMPERATURE.CAT

6. CHEMICAL PACKAGE TYPE: VX - Missile

SIDE....TYPE....LETHALITY....DELIVERY.SYSTEM....ROUNDS.REQUIRED

SIDE	TYPE	LETHALITY	DELIVERY.SYSTEM	ROUNDS.REQUIRED
2	P	0.2	SCUD	1

RADIUS(KM).AND.DOWNWIND.STRETCH.DISTANCE(KM).AND.PERSISTENCY (MIN).BY.WIND.AIR.STAB.CAT.BY.TEMPERATURE.CAT

WIND.AIR. TEMPERATURE.CATEGORY

STAB.CAT	1	2	3	4	5	6
1	.1 0 2000000	.6 0 300000	.8 0 60000	.8 0 14000	.8 0 3000	.9 0 1000
2	.1 0 3000000	.2 0 300000	.8 0 50000	.8 0 12000	.6 0 3000	.6 0 1000
3	.1 0 4000000	.4 0 200000	.4 0 50000	.4 0 12000	.4 0 3000	.4 0 900

END.RADIUS(KM).AND.DOWNWIND.STRETCH.DISTANCE(KM).AND. PERSISTENCY(MIN).BY.WIND.AIR.STAB.CAT.BY.TEMPERATURE.CAT

APPENDIX D: Sample Data

The U.S. Army Chemical School will provide actual classified degradation factors and chemical weapons capabilities prior to conducting any analysis utilizing JWAEP, however, a set of reasonable unclassified data is provided. The source for this data is the TACWAR model [20, 26].

Perception Threshold: 0.4

Temperature Classes and Range (Degrees Fahrenheit)

Class:	1	2	3	4	5	6
Range:	-50-40	41-60	61-80	81-100	100-120	121-160

Wind Speed /Air Stability Classes

	Air Stability			
Wind Speed	STABLE	NEUTRAL	UNSTABLE	ALL
0 - 4				1
5 - 10				2
11 - 25	3	4	5	

Lethality Reduction Factors

	Unit Protective Levels			
	Side 1		Side 2	
Agent Type	PP	FP	PP	FP
Non-Persistent	.75	.02	.75	.02
Persistent	.65	.02	.65	.02

Effectiveness Degradation Factors (EDF)

Protective Level: Unit Category	Temp. Range	Unit Activities						
		Attack	Defend	Delay	Move to Contact	Unopp. Move	Spt	TAA
PProt: Armor/Mech	1	.87	.92	.89	.88	.9		.8
Motorized		.84	.88	.86	.85	.85		.8
Infantry		.78	.82	.8	.79	.8		.8
Artillery						.85	.85	.8
Aviation		.88	.92	.9	.89	.9		.8
Armor/Mech	2	.83	.87	.84	.84	.85		.7
Motorized		.77	.83	.79	.78	.8		.7
Infantry		.7	.74	.72	.73	.75		.7
Artillery						.8	.8	.7
Aviation		.8	.87	.83	.82	.85		.7
FProt: Armor/Mech	1	.79	.85	.82	.81	.85		.6
Motorized		.7	.77	.73	.72	.75		.6
Infantry		.6	.7	.65	.62	.65		.6
Artillery						.7	.6	.6
Aviation		.7	.8	.75	.74	.8		.6
Armor/Mech	2	.7	.8	.75	.74	.8		.5
Motorized		.65	.72	.68	.67	.7		.5
Infantry		.55	.7	.58	.57	.6		.5
Artillery						.65	.55	.5
Aviation		.67	.75	.73	.7	.75		.5

Sample Adjustment Parameters for Penetration Distance

Unit Posture	Chemical Packages			
	NP - G	P - VX	NP - CK	P - L
1. Stationary				
Parameter 1	A=0.0 B=0.0	N/A	A=0.25 B=0.0	N/A
Parameter 2	A=0.5 B=0.0	N/A	A=1.0 B=0.0	N/A
2. Moving				
Parameter 1	A=0.25 B=0.0	A=0.0 B=0.0	A=0.25 B=0.0	A=0.0 B=0.0
Parameter 2	A=1.0 B=0.0	A=1.0 B=0.0	A=1.0 B=0.0	A=1.0 B=0.0

APPENDIX E: Derivation of Equations (4-8)

R_U = unit radius
R_C = initial dispersion radius of chemical package
d = the distance between the aim point and center mass of a unit
x = x axis value where intersection of unit and chemical package radii occurs upon initial dispersion of chemical package during employment
y = y axis value where intersection of unit and chemical package radii occurs upon initial dispersion of chemical package during employment

Assume: R_U is always centered at the origin in an arbitrary Cartesian plane
R_C is centered on the y axis of the Cartesian plane

Equation for Unit:

$$x^2 + y^2 = R_U^2$$
$$x = \pm\sqrt{R_U^2 - y^2}$$
$$y = \pm\sqrt{R_U^2 - x^2}$$

Equation for Chemical Package:

$$x^2 + (y - d)^2 = R_C^2$$
$$x = \pm\sqrt{R_C^2 - (y-d)^2}$$
$$y = \pm\sqrt{R_U^2 - x^2} + d$$

To determine where the intersection of the radii occurs on the Cartesian plane:

$$\pm\sqrt{R_U^2 - y^2} = \pm\sqrt{R_C^2 - (y-d)^2}$$

Solving for y:

$$y = \frac{R_U^2 + d^2 - R_C^2}{2 * d} \qquad \text{Equation (4)}$$

From above, x:

$$x = \pm\sqrt{R_U^2 - y^2} \qquad \text{Equation (5)}$$

Area between two curves (ABTC) = $\int_a^b [f(x) - g(x)]\,dx$

where $f(x) = \pm\sqrt{R_U^2 - x^2}$ and $g(x) = \pm\sqrt{R_U^2 - x^2} + d$

Therefore,

$$ABTC = \int_{-x}^{x} \pm\sqrt{R_U^2 - x^2}\,dx - \int_{-x}^{x} \pm\sqrt{R_C^2 - x^2}\,dx - \int_{-x}^{x} d\,dx$$

These integrals are of the form $\int \sqrt{a^2 - x^2}\,dx$.

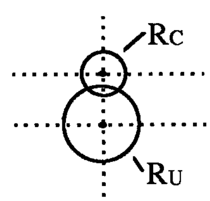
Using integral tables: $\int \sqrt{a^2 - x^2}\,dx = .5*\left(x*\sqrt{a^2 - x^2} + a^2*\sin^{-1}\left(\frac{x}{a}\right)\right)$

Substituting,

$$ABTC = \begin{bmatrix} \pm\left[.5*\left(x*\sqrt{R_U^2 - x^2} + R_U^2*\sin^{-1}\left(\frac{x}{a}\right)\right)\Big|_{-x}^{x} \right] - \\ \pm\left[.5*\left(x*\sqrt{R_C^2 - x^2} + R_C^2*\sin^{-1}\left(\frac{x}{a}\right)\right)\Big|_{-x}^{x} \right] \end{bmatrix} - 2*d*x$$

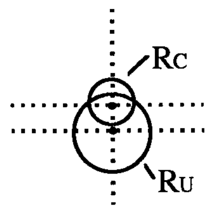
The appropriate sign for f(x) and g(x) is dependent upon the position of their respective arcs between the intersection points in relation to their center. Also, depending upon this position, the equation determines either the area of overlap between the chemical package and unit or the area of one *not* overlapping the other. Specifically, there are three cases to consider:

Case 1: The equation uses the positive arc from R_U (f(x)) and the negative arc from R_C (-g(x)) and determines the *area of overlap* ***between*** the chemical package and unit. Therefore, $y \geq 0$ and $\leq d$.



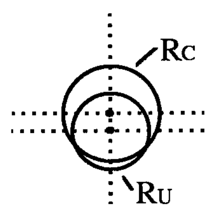
$$ABTC = \begin{bmatrix} \left[.5*\left(x*\sqrt{R_U^2 - x^2} + R_U^2*\sin^{-1}\left(\frac{x}{a}\right)\right)\Big|_{-x}^{x} \right] + \\ \left[.5*\left(x*\sqrt{R_C^2 - x^2} + R_C^2*\sin^{-1}\left(\frac{x}{a}\right)\right)\Big|_{-x}^{x} \right] \end{bmatrix} - 2*d*x$$

Case 2: The equation uses the positive arc from R_C (g(x)) and the positive arc from R_U (f(x)) to determine the *area of the chemical package* ***not*** overlapping the unit. Therefore, $y \geq 0$ and $\geq d$.



$$ABTC = \left[\left[.5*\left(x*\sqrt{R_C^2 - x^2} + R_C^2*\sin^{-1}\left(\frac{x}{a}\right)\right)\Bigg|_{-x}^{x} \right] - \left[.5*\left(x*\sqrt{R_U^2 - x^2} + R_U^2*\sin^{-1}\left(\frac{x}{a}\right)\right)\Bigg|_{-x}^{x} \right] \right] - 2*d*x$$

Case 3: The equation uses the negative arc from R_C (-g(x)) and the negative arc from R_U (-f(x)) to determine the *area of the unit* ***not*** overlapping the chemical package. Therefore, $y \leq 0$.



$$ABTC = \left[-\left[.5*\left(x*\sqrt{R_C^2 - x^2} + R_C^2*\sin^{-1}\left(\frac{x}{a}\right)\right)\Bigg|_{-x}^{x} \right] + \left[.5*\left(x*\sqrt{R_U^2 - x^2} + R_U^2*\sin^{-1}\left(\frac{x}{a}\right)\right)\Bigg|_{-x}^{x} \right] \right] - 2*d*x$$

Utilizing the ABTC, the fraction of unit coverage, $Cov_{(i)}$, due to employment of chemical packages is determined depending upon the applicable case:

Case 1:

$$Cov_{(i)} = \frac{ABTC}{\pi * R_U^2}$$

$$Cov_{(i)} = \frac{\left[\begin{array}{l}\left[.5*\left(x*\sqrt{R_U^2 - x^2} + R_U^2 * \sin^{-1}\left(\frac{x}{R_U}\right)\right) - .5*\left(-x*\sqrt{R_U^2 - x^2} + R_U^2 * \sin^{-1}\left(\frac{-x}{R_U}\right)\right)\right] + \\ \left[.5*\left(x*\sqrt{R_C^2 - x^2} + R_C^2 * \sin^{-1}\left(\frac{x}{R_C}\right)\right) - .5*\left(-x*\sqrt{R_C^2 - x^2} + R_C^2 * \sin^{-1}\left(\frac{-x}{R_C}\right)\right)\right]\end{array}\right] - 2*d*x}{\pi * R_U^2}$$

Equation (6)

Case 2:

$$Cov_{(i)} = \frac{\pi * R_C^2 - ABTC}{\pi * R_U^2}$$

$$Cov_{(i)} = \frac{\pi * R_C^2 - \left[\begin{array}{l}\left[.5*\left(x*\sqrt{R_C^2 - x^2} + R_C^2 * \sin^{-1}\left(\frac{x}{R_C}\right)\right) - .5*\left(-x*\sqrt{R_C^2 - x^2} + R_C^2 * \sin^{-1}\left(\frac{-x}{R_C}\right)\right)\right] - \\ \left[.5*\left(x*\sqrt{R_U^2 - x^2} + R_U^2 * \sin^{-1}\left(\frac{x}{R_U}\right)\right) - .5*\left(-x*\sqrt{R_U^2 - x^2} + R_U^2 * \sin^{-1}\left(\frac{-x}{R_U}\right)\right)\right]\end{array}\right] - 2*d*x}{\pi * R_U^2}$$

Equation (7)

Case 3:

$$Cov_{(i)} = \frac{\pi * R_U^2 - ABTC}{\pi * R_U^2}$$

$$Cov_{(i)} = \frac{\pi * R_U^2 + \left[\begin{array}{l}\left[.5*\left(x*\sqrt{R_C^2 - x^2} + R_C^2 * \sin^{-1}\left(\frac{x}{R_C}\right)\right) - .5*\left(-x*\sqrt{R_C^2 - x^2} + R_C^2 * \sin^{-1}\left(\frac{-x}{R_C}\right)\right)\right] - \\ \left[.5*\left(x*\sqrt{R_U^2 - x^2} + R_U^2 * \sin^{-1}\left(\frac{x}{R_U}\right)\right) - .5*\left(-x*\sqrt{R_U^2 - x^2} + R_U^2 * \sin^{-1}\left(\frac{-x}{R_U}\right)\right)\right]\end{array}\right] - 2*d*x}{\pi * R_U^2}$$

Equation (8)

APPENDIX F: Definition of Variables

$NProt_{Overall}$ = the overall fraction of unit in no protection
$PProt_{Overall}$ = the overall fraction of unit in partial protection
$FProt_{Overall}$ = the overall fraction of unit in full protection
Eff_{PProt} = the effectiveness degradation for personnel in partial protection while performing a specific activity
Eff_{FProt} = the effectiveness degradation for personnel in full protection while performing a specific activity
$Eff_{Overall}$ = the overall effectiveness of a unit performing an activity
R_U = unit radius
R_C = initial dispersion radius of Chemical Package
d = the distance between the aim point and center mass of a unit
x = x axis value where intersection of unit and chemical package radii occurs upon initial dispersion of chemical package during employment
y = y axis value where intersection of unit and chemical package radii occurs upon initial dispersion of chemical package during employment
i = a separate encounter with a chemical package
$Attr_{DL}$ = the number of personnel losses due to the initial dispersion or discovery of chemical packages
$Attr_{DWH}$ = the number of personnel losses due to the downwind hazard of non-persistent chemical packages
$Attr_{Employ}$ = the total number of personnel losses due to employment effects
$Attr_{Discovery}$ = the total number of personnel losses due to discovery effects
$Attr_{Bull}$ = the total number of personnel losses due to bull-through effects
L = the lethality of the chemical package
L_{FProt} = the lethality reduction factor for personnel in full protection
L_{PProt} = the lethality reduction factor for personnel in partial protection
PS = the current personnel strength of the unit prior to the chemical package encounter
SCALE = the scaling factor used to determine the fraction of unit contained within the downwind hazard area subject to downwind hazard losses
θ = the angle used to determine the parameters for calculating the fraction of unit forced into full protection due to encounters with non-persistent chemical packages (degrees)
SPEED = the speed used to determine both the amount of time a unit remains in full protection due to a non-persistent cloud encounter and the adjusted penetration distance due to discovery (meters per minute)
TIME = the period of time the fraction of unit forced into full protection must remain in full protection due to a chemical package encounter (minutes)
$Cloud_{Orient}$ = the global wind direction (degrees)
$Unit_{Orient}$ = the direction in which the unit is oriented (degrees)
Facet = the dimension of a unit that initially encounters a chemical package

Other Facet = the dimension of a unit that does not initially encounter a chemical package
Length = a unit's formation length across its front (meters)
Width = a unit's formation width or depth (meters)
LWS = the local wind speed (meters per minute)
UMR = the instantaneous unopposed movement rate for a unit (meters per minute)
P_t = the remaining persistency of a chemical package (minutes)
DSD = the downwind stretch distance of a non-persistent chemical package
ES = the current equipment strength of the unit prior to the chemical package encounter.
Density = the density of a unit or the number of pieces of equipment which occupy one square meter of space.
$Lines_{Aff}$ = the number of unit lines affected by the adjusted penetration distance
$Line_{Density}$ = the density of a unit across it's lines (number of pieces of equipment per linear meter)
$Dist_{Lines}$ = the distance between unit lines within a unit formation (meters)
$Dist_{Raw\ Pen}$ = the raw distance a chemical package penetrates into a unit formation due to discovery
$Dist_{Adj\ Pen}$ = the adjusted distance a chemical package penetrates into a unit formation due to discovery
T_{Dis} = the discovery time associated with encountering previously unknown persistent chemical packages (minutes)
T_R = the time required to conduct a chemical reconnaissance of a perceived persistent chemical package (minutes)
T_{Sur} = the time required to conduct a chemical survey of a persistent chemical package (minutes)
T_{Sam} = the time required to complete a chemical survey sample (minutes)
D_{BS} = the distance between survey samples (meters)
T_{BS} = the time required to travel between samples (minutes)
T_{By} = the time required to bypass a persistent chemical package (minutes)
T_{Bull} = the time required to bull-through a chemical package (minutes)
$T_{DeconOp}$ = the time required to perform operational decontamination
$T_{DeconThor}$ = the time required to perform thorough decontamination
Cont = the fraction of unit contaminated due to an encounter with a chemical package
Cov = the initial fraction of unit covered due to an encounter with a chemical package
FProt = the fraction of unit that assumes full protection due to an encounter with a chemical package
PProt = the fraction of unit that assumes partial protection due to an encounter with a chemical package
$Decon_{Resources}$ = the number of decontamination resources available to perform decontamination operations
$Decon_{OpRate}$ = the rate at which one decontamination resource performs operational decontamination
$Decon_{ThorRate}$ = the rate at which one decontamination resource performs thorough decontamination

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13. ABSTRACT *(Maximum 200 words)*

This thesis describes the development of a methodology to model chemical weapons use in the Joint Staff's Joint Warfare Analysis Experimental Prototype (JWAEP) and to quantify the resulting effects. The methodology incorporates organic unit assets and theater-level chemical assets into JWAEP by using the three principles of nuclear, biological, and chemical defense (NBC) which reflect joint and Army doctrine, and combines them with the basic concepts already used in existing theater-level models. Other aspects of the problem include representing chemical "packages" on the battlefield, determining attrition and time effects, adjusting unit effectiveness, determining chemical package intelligence acquisition procedures, identifying solution techniques, verifying the results, and making recommendations. The proposed solution techniques provide a feasible methodology for integrating high resolution modeling into a low resolution model. The algorithms incorporate the chemical estimate process, Mission Oriented Protective Posture (MOPP) analysis, and employment of appropriate doctrinal unit tactics based on a perception of existing or potential chemical weapons use. Thus, the methodology provides accurate input into the JWAEP for approximating real world results as well as a structured and quantifiable framework reflecting joint and Army doctrine that can be used for stand alone chemical effects analysis.

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