# Combat Airbase Sortie Degrade Methodology for Theater Campaign Analysis

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*Abstract.* In combat simulation models, with resolution at the theater level, it is highly desirable to account for the degradation of a combat airbase's ability to generate combat power when the enemy attacks the combat airbase. A sortie degrade, or similar measure of such a loss, should be computed in this case to reflect the consequent militation against the level of close air support for battlefield troops. Not all theater-level simulations model this effect.

In this paper, we develop a methodology for determining the effects of threat Theater Ballistic Missiles (TBMs) armed with chemical warheads on sortie generation at a combat airbase that improves on previous efforts in that we determine the functional areas, or nodes, of the combat airbase by considering the combat airbase's geospatial and functional properties. The nodes are connected by transport routes, thus imparting a network. This network, in turn, is used as the basis for computing the times to generate a sortie in a clean and contaminated environment. Multiple sortie types are also accounted for in this methodology.

Not all the nodes have the same probability of being contaminated by the chemical TBM attack. This methodology is unique in considering these multiple, non-uniform, network-based probabilities for computing the sortie generation times in a contaminated environment, and thus the sortie degrade. We found that an existing method for calculating weapon effects of conventional munitions on a target, the Single-Shot Probability of Destruction, or SSPD, can be used in determining these probabilities. SSPD is a recognized method for calculating weapon effects, and we show how it is incorporated into the wider methodology we designed and implemented for computing combat airbase sortie degrades.

*Keywords.* Air defense, sortie degrade, chemical attack, sortie generation network, combat airbase, lethal area, sortie type, sortie capacity, theater ballistic missile, weaponeering.

## 1. Background

Capturing the effects of high-explosive or chemical attacks on combat bases or units in a simulation model has been a highly desired capability for simulation-based analytical studies. A prime example of this is in computing the effects of threat attacks on combat airbases, and especially the combat airbase's consequent loss of the ability to generate combat power. That loss is typically expressed in terms of *sortie degrade*, a factor which is applied to the combat airbase's combat sortie generation capability measured under optimal, or non-adverse, conditions. Studies that have contributed to the effort of capturing or estimating such effects include the 1997 Coral Breeze study, the Operational Availability 2004 study, the Operational Availability 2005 study, the Joint Weapons of Mass Destruction Analysis, and the Carlucci Combat Airbase Model.

Prior to these studies, attempts at capturing the effects of chemical attacks on combat airbases were crude: at the sound of the Theater Ballistic Missile (TBM) warning alarm on a combat airbase, the entire airbase would operate at Mission-Oriented Protective Posture (MOPP) level 4. The sortie degrade was applied for the entire duration of the chemical persistency and was wholly attributable to personnel conducting sortie generation operations in chemical protective overgarments.

The Coral Breeze study was one of the first attempts to apply some analytical rigor to the degrade calculation. This study, and ones that followed it, considered the size of the chemical plumes due to an attack by TBMs armed with chemical warheads relative to the size of the combat airbase; the percentage of the combat airbase that could be maximally covered by such plumes was calculated and applied. However, the layout and the sortie generation capacity of the combat airbase on the day of the chemical attack were not elements of the sortie degrade calculation (USCINCPAC 1997).

The Joint Weapons of Mass Destruction Analysis looked more comprehensively at the sortie generation operation on a combat airbase but determined the sortie degrade factors based solely on the number of chemical attacks (J-8/WAD 1996). The Operational Availability 2004 study and the subsequent 2005 study were the first attempts to incorporate the layout of the combat airbase into the sortie degrade calculation. The impact points of the chemical TBM attacks were randomly chosen from the stochastic Extended Air Defense Simulation (EADSIM) model. The chemical plumes, computed by the Vapor, Liquid, and Solid Tracking (VLSTRACK) computer model, were placed on top of the layout of the combat airbase to calculate the area of contamination, and sortie generation subject matter experts determined what the sortie degrade would be (OSD/PA&E(SAC) 2004) (J-8/WAD 2005).

The Center for Army Analysis (CAA) used an internal model, called the Carlucci Combat Airbase Model and documented in Carlucci (1999, unpublished paper), which took the findings of the Coral Breeze study and attempted to incorporate the sortie capacity inherent to a particular airbase, as well as the VLSTRACK chemical plume size, in the calculation of the sortie degrade.

## 2. Problem Statement & Approach

We conducted a study at CAA, called *Combat Airbase Sortie Degrade Methodology* and reported in Rothwell & Chang (2009), that improved upon previous studies by determining a sortie generation network utilizing an actual combat airbase layout in the form of satellite imagery; this, in turn, was the basis for computing the task times for different sortie types. And whereas previous studies computed a uniform probability of contamination for the combat airbase, we used the Joint Munitions Effectiveness Manual's (JMEM) Single-Shot Probability of Destruction (SSPD) approach and the sortie generation network to compute multiple non-uniform probabilities of contamination for the combat airbase.

The problem that our study addressed is how to determine the effects of threat Theater Ballistic Missiles (TBMs) armed with chemical warheads on sortie generation at a combat airbase, and how to represent these effects in the campaign analysis in the Joint Integrated Contingency Model (JICM), DoD's land-force, theater-level campaign model. We accomplished this by designing and implementing a methodology for determining the sortie degrade factors at combat airbases due to chemical threat TBM hits. These factors are then used as inputs for JICM runs.

At the heart of the new sortie degrade methodology is the idea, contributed by Mr. Paul Chang, CAA, of using the SSPD approach to determine the likelihood of contamination on different parts of the combat airbase. SSPD is a proven approach used by the Joint community and is normally used to estimate the effectiveness of air-launched and surface-launched conventional munitions on targets (Driels 2004). Indeed, this approach is not new to campaign analysis conducted at CAA since CAA's campaign analysts currently receive Air-to-Surface munition Probabilities of Kill (PKs) for use in JICM from J-8, which computes them by way of the SSPD functionality inherent in the JMEM Weaponeering System model.[1]

To address the study purpose, we had to determine the increase in the time needed to generate sorties after a TBM chemical attack on a combat airbase. The essential elements of the analysis included determining the sortie generation times in a clean environment and in a contaminated environment. Measures used in this study included generation times by sortie type, aircraft, and day at each combat airbase.

Additionally, we had to understand combat airbase operations and the network, or paths, that sortie generation follows. This, along with the SSPD and the aforementioned measures, was the basis for calculating the time required to generate a sortie.

As in other studies, a chemical hazard plume generated by VLSTRACK was created to represent the lethal area of the attack. However, while we used VLSTRACK plumes for the lethal areas, any representation that conformed to the methodology's conditions would have sufficed. As we shall see in the following discussion, the methodology abstractly defines lethal area, so that it is not necessarily restricted to a particular concrete representation.

## 3. Assumptions

The main assumption of this study is that threat forces have detailed information concerning targeted combat airbases, including weather, key infrastructure location and functionality, and sortie generation specifications. This not only implies that the target location error is zero, but that an even stronger condition prevails: that the enemy will be able to infer the combat airbase sortie generation network, and thus identify the major bottleneck in the network and use this as the aimpoint.

Also, in computing delivery accuracy, we assume no weapon bias, or ballistic dispersion error, in keeping with weaponeering and artillery practice. For more information see the discussion in Driels (2004), pages 57–60.

Once we assume that a chemical attack occurs, airmen will conduct sortie generation operations in chemical protective overgarments and will not deviate from established Tactics, Techniques, and Procedures (TTPs).

For the purpose of the study, we assumed March weather with an average temperature of 50 degrees Fahrenheit, or 10 degrees Celsius. The chemical persistency of VX, a persistent nerve agent, on a concrete surface in the study's timeframe, is 24 hours, based on vapor hazard duration estimates in AFMAN 10-2602 (2003).

Finally, we assume that multiple simultaneous TBM hits are probabilistically independent events.

## 4. Methodology

The steps involved in the new sortie degrade methodology are:

- Identify combat airbase sortie generation network and bottleneck (aim point).
- Calculate sortie generation time in a clean environment for each sortie type.
- Calculate the Single Shot Probability of Contamination (SSPC) for each node in the critical path.
- Calculate expected sortie generation time in a contaminated environment for each sortie type.
- Determine combat airbase sortie generation capacity for each sortie type.
- Use this data to generate the overall combat airbase sortie degrade. This process is repeated each day to create a daily combat airbase sortie degrade.
- Before the application process in JICM, the sortie degrade factor is compared against the weather degrade factor and the larger of the two is applied against the combat airbase for that day.

4.1. **Calculating SSPD.** SSPD is a measure of the effectiveness of a single weapon directed against a unitary target. Indeed, Driels (2004), in developing the computational forms for SSPD, considered the unitary target in this case to be a point target. This was in line with the conditions

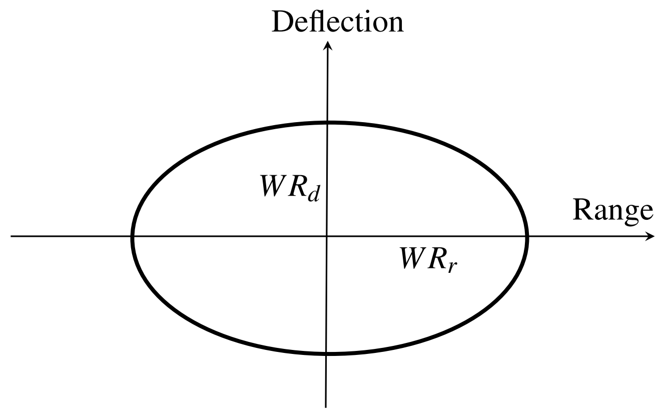


FIGURE 1. Plume footprint

of our data, namely that the lethal area of the weapons we considered were far larger than the size of any unitary target in question.[2]

Given the density function of the delivery accuracy of the weapon $g(x)$ and the one-dimensional Carleton damage function $c(x)$, Driels (2004) defines SSPD as

$$\text{SSPD} = \text{SSPD}_x \times \text{SSPD}_y$$

where

$$\text{SSPD}_x = E[c(x)] = \int_{-\infty}^{\infty} c(x)g(x)\,dx,$$

and $\text{SSPD}_y$ is defined similarly.

The VLSTRACK plume, which represents the lethal (and effective) area as an ellipse, can be viewed as lethal area representation corresponding to the lethality of a Carleton damage function (see Figure 1). Also, the Carleton damage function can be shown to be approximated by a simpler bounded function over a finite rectangular region while conserving lethality.[3] The dimensions of the rectangular region are the *effective target length* $L_{ET}$ and the *effective target width* $W_{ET}$ (see Figure 2).

A result from Driels (2004) states that, given that the damage function in question, derived from a Carleton form, has a bounded rectangular domain with dimensions $L_{ET}$ and $W_{ET}$, then

$$\text{SSPD} = \frac{L_{ET}W_{ET}}{\sqrt{(17.6\text{REP}^2 + L_{ET}^2)(17.6\text{DEP}^2 + W_{ET}^2)}}, \tag{1}$$

where REP is the *range error probable* and DEP is the *deflection error probable*—both of which are descriptors of the delivery accuracy.

However, we don't immediately have REP and DEP; instead we have another descriptor of weapon delivery accuracy, namely *circular error probable* (CEP), a measure of the variation of the delivery

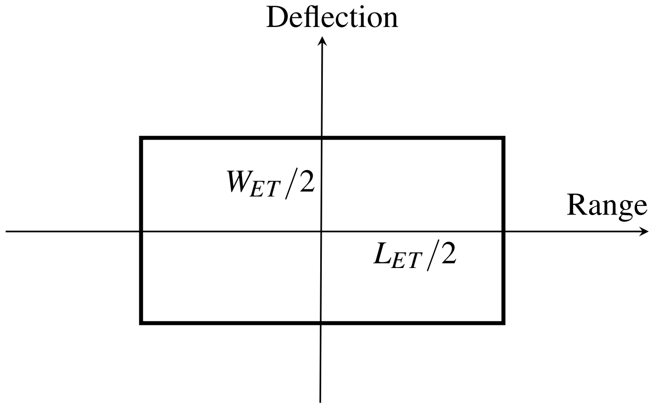


FIGURE 2. Rectangular lethal area

error, which is normally distributed with standard deviation $\sigma = \text{CEP}/1.177$. (We take all the means of these distributions to be zero, without loss of generality.) If we assume that the errors in the $x$ (range) and $y$ (deflection) directions are independent, identically distributed and normal with standard deviations $\sigma_x$ and $\sigma_y$ respectively, we can obtain a relation between CEP, REP, and DEP. However, we have to make one more simplifying assumption, namely that $\sigma_x = \sigma_y = \sigma$. This implies that

$$\text{REP} = \text{DEP} = (0.5731)\text{CEP}.$$

Now, only $W_{ET}$ and $L_{ET}$ remain to be determined to compute SSPD by way of Equation (1).

To do this we translate the plume's elliptical representation of the lethal area into a rectangular representation, keeping the area and aspect ratios of both equal; this preserves lethality, as mentioned earlier. The area of the ellipse is given by

$$A = \pi \times WR_r \times WR_d,$$

where $WR_r$ and $WR_d$ are the *weapon radii* in the range and deflection directions respectively, cf. Figure 1. The aspect ratio of the ellipse is $a = WR_r/WR_d$. Then

$$L_{ET} = \sqrt{aA} \;\text{ and }\; W_{ET} = L_{ET}/a,$$

which preserves the area, i.e. $A = L_{ET}W_{ET}$, and aspect ratio, i.e. $a = L_{ET}/W_{ET}$.

Since the threat type under consideration for this study were TBMs with chemical warheads, we styled SSPD as *Single Shot Probability of Contamination,* or SSPC, and for the rest of the paper we will use the SSPC nomenclature.

To see an example of calculating the SSPC, suppose that the threat target (aim point) is the Air to Surface Munitions Assembly Area (ASMAA), the weapon system is a TBM with a missile CEP

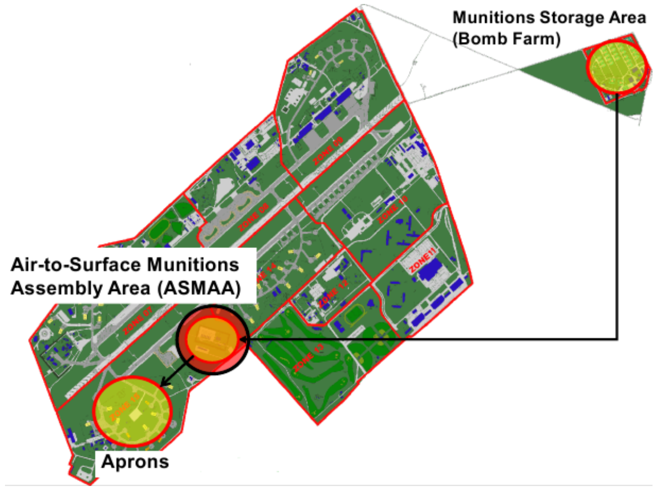


FIGURE 3. Critical Path on CAB A

of 250 meters and armed with VX nerve agent, and the effective target length and width are 6000 and 800 meters respectively. Then, the probability of contaminating the ASMAA is

$$\begin{aligned}
\text{SSPC} &= \frac{L_{ET}W_{ET}}{\sqrt{(17.6\text{REP}^2 + L_{ET}^2)(17.6\text{DEP}^2 + W_{ET}^2)}} \\
&= \frac{(6000)(800)}{\sqrt{(17.6(0.5731 \cdot 250)^2 + 6000^2)(17.6(0.5731 \cdot 250)^2 + 800^2)}} \\
&\approx 0.7955.
\end{aligned}$$

4.2. **Critical Path & Calculating Clean Sortie Generation Time.** Sortie generation time depends, in part, on the number of sortie generation nodes (functional areas) on the combat airbase and the distances between those nodes. This information is specific to a particular combat airbase in question.

Consequently, the methodology requires certain geospatial data about the combat airbase, to identify critical sortie generation paths and the threat target nodes. A map of a notional combat airbase, which we call CAB A, is depicted in Figure 3. The nodes that comprise the sortie generation network for this combat airbase include the munitions storage area, the ASMAA, and the aprons. The bottleneck in the sortie generation process, at which threat forces are assumed to aim, was the ASMAA.

We can calculate the time to generate a sortie (for a fixed sortie type), if we know the time to accomplish the task (called *task time*) at a each node and the travel times between nodes. Our source for task times was Lawrence et al (2001), which gives average munition time requirements, and we allowed 10 minutes for movement between any two adjacent nodes.

Hence, for a network with $N$ nodes and a fixed sortie type, if $c_i$ is the task time in a clean environment for node $i$, and $t_i$ is the travel time between node $i$ and node $i+1$, then the sortie generation time in a clean environment, $C$, is given by

$$C = \sum_{i=1}^{N} c_i + \sum_{i=1}^{N-1} t_i. \tag{2}$$

The following table is an example of calculating the sortie generation time in a clean environment for a Battlefield Air Interdiction (BAI) sortie mission for a Type 1 aircraft from CAB A, which results in $C = 140$ minutes to generate the sortie.

| Task and Travel Times | Clean Sortie Generation Time (min) |
|---|---|
| Bomb Farm (BF) prepares required munition | 30 |
| Munitions move from BF to ASMAA | 10 |
| Air-to-Surface munition assembled | 60 |
| Munitions move from ASMAA to Apron | 10 |
| Aircraft serviced at Apron | 30 |
| Total Time | 140 |

4.3. **Calculating Contaminated Sortie Generation Time.** In a contaminated environment, the task time at each node will increase (or alternatively, the node's "throughput" will degrade) due to the fact that personnel have to perform their work wearing chemical protective overgarments. AFMAN 32-4005 (2001) contains time degrade factors, called *task time multipliers* or TTMs, which reflect the degrade and depend upon activity, type of work, and weather conditions. We apply the factor 2.1 for heavy work and 1.4 for moderate work.

Then at any node, the task time in a contaminated environment is the product of the task time in clean environment and the TTM for that node.

Hence, for a network with $N$ nodes and a fixed sortie type, if $c_i$ is the task time in a clean environment for node $i$, $t_i$ is the travel time between node $i$ and node $i+1$, $\alpha_i$ is the TTM for node $i$, and $\beta_i$ is the TTM for travel between nodes $i$ and $i+1$, then the sortie generation time in a contaminated environment, $D$, is given by

$$D = \sum_{i=1}^{N} \alpha_i c_i + \sum_{i=1}^{N-1} \beta_i t_i.$$

We allowed $\beta_i = 1.4$ for all $i,\ 1 \leq i < N$.

Returning to our example, it is possible to calculate the amount of time it takes to generate the Type 1 Aircraft BAI sortie mission at CAB A in a contaminated environment.

| Task and Travel Times | Clean Sortie Generation Time (min) | TTM | Contaminated Sortie Generation Time (min) |
|---|---|---|---|
| Bomb Farm (BF) prepares required munition | 30 | 2.1 | 63 |
| Munitions move from BF to ASMAA | 10 | 1.4 | 14 |
| Air-to-Surface munition assembled | 60 | 2.1 | 126 |
| Munitions move from ASMAA to Apron | 10 | 1.4 | 14 |
| Aircraft serviced at Apron | 30 | 1.4 | 42 |
| Total Time | $C = 140$ | | $D = 259$ |

This table assumes all parts of the sortie generation network are contaminated. An expected value method is discussed in section 4.4 to account for the fact that, in general, the entire base is not contaminated.

4.4. **Collateral Damages & Expected Sortie Generation Time.** Another step in the study's methodology which must be addressed is the calculation of collateral damage. The methodology examines the possibility of contaminating nodes other than the target node (aim point) in the sortie generation network.

This case is covered by Driels (2004), which has a more general version of the component-wise SSPC definition of Equation (1) that accounts for offsets in the range and deflection directions between the target node and each of the other nodes. Given $R_0$, the offset in the range direction, $\mathrm{SSPC}_x$ is more generally stated by

$$\mathrm{SSPC}_x = \frac{L_{ET}}{\sqrt{17.6\mathrm{REP}^2 + L_{ET}^2}} \cdot \exp\left[-\frac{4R_0}{17.6\mathrm{REP}^2 + L_{ET}^2}\right],$$

and $\mathrm{SSPC}_y$ is defined similarly, with the offset in the deflection direction denoted by $D_0$. Note that when $R_0 = D_0 = 0$, we have Equation (1), as expected.

For every node $i$ in the sortie generation network, we compute the offset version of SSPC and call it $p_i$. With this, we are able to find the expected value of the sortie generation time in a contaminated environment, which allows us to drop the strong, and less desirable, condition of section 4.3, namely that all the nodes in the network are contaminated with probability 1. This is

$$D' = \sum_{i=1}^{N} (p_i d_i + q_i c_i) + \sum_{i=1}^{N-1} \beta_i t_i, \tag{3}$$

with $d_i = \alpha_i c_i$ and $q_i = 1 - p_i$.

Finally, the sortie degrade factor can now be expressed by the following.

$$\mathrm{SD} = 1 - \frac{C}{D'}.$$

This degrade, however, is only for one sortie type. Additional work is needed to compute the sortie degrade factor for the entire combat airbase.

4.5. **Sortie Types & Capacity.** Now that we know how to calculate the sortie degrade for one instance of one sortie type, to compute the daily sortie degrade, we must consider the daily capacity (i.e., how many sorties can be generated in a day) of all sortie types on the combat airbase.

For this study, the air campaign data was provided by CAA campaign analysts and is comprised of four files: the Airbase, Air Summary Display, Air Tasking Order, and Munitions Loading files. These files are merged to create a master air campaign database, which contains sortie missions by aircraft type, sortie rates by aircraft type and mission (i.e. sortie type), number of aircraft at each combat airbase per day, and number of munitions required per sortie type.

With air campaign input, a combat airbase's capacity can be determined by the number of aircraft and the sortie rate per mission type. A maximum sortie value is computed by multiplying the number of aircraft and the sortie rate for that mission.

We now compute a combat airbase's daily capacity by way of example. Suppose that, on a particular day, CAB A has three sortie types: Aircraft 1 and Aircraft 2 for BAI missions and Aircraft 3 for escort missions. Then the daily capacity for CAB A can be computed by the following table.

| Sortie Type | No. of Aircraft | Sortie Rate | Max Sorties |
|---|---|---|---|
| Aircraft 1 (BAI) | 22 | 1.5 | 33 |
| Aircraft 2 (BAI) | 17 | 1.5 | 25 |
| Aircraft 3 (Escort) | 6 | 1.5 | 9 |
| | | Total Sorties | 67 |

In this example, CAB A has a maximum capacity of 67 sorties on this day of the campaign.

4.6. **Sortie Degrade For One TBM Hit.** Now, we can calculate the sortie degrade for the combat airbase on a particular day that is caused by a single hit of a threat TBM on the combat airbase.

First, we calculate the combat airbase's sortie generation time for all the day's sorties in a clean environment. This is based on the (day's) sortie capacities. For each sortie type $i$, $1 \leq i \leq M$, the product of the sortie capacity $k_i$ and the sortie generation time in a clean environment $C$, for that type (which we style as $C_i$ now), and which was defined by Equation (2), is the total sortie generation time in a clean environment for sortie type $i$. Then the sum of these times is the sortie generation time in a clean environment for the entire combat airbase (on a particular day), that is

$$C^* = \sum_{i=1}^{M} k_i C_i.$$

Returning to the example with $M = 3$ sortie types, $C^*$ might be computed like the following.

| Sortie Type | $i$ | Capacity $k_i$ | Clean Time $C_i$ (min) | Total Sortie Gen. Time (min) |
|---|---|---|---|---|
| Aircraft 1 (BAI) | 1 | 34 | 180 | 6120 |
| Aircraft 2 (BAI) | 2 | 25 | 225 | 5625 |
| Aircraft 3 (Escort) | 3 | 9 | 145 | 1305 |
| | | | | $C^* = 13,050$ |

The sortie generation time in a contaminated environment for the entire combat airbase (on a particular day) is computed similarly.

$$D^* = \sum_{i=1}^{M} k_i D_i'.$$

In this case, $D_i'$ is the expected sortie generation time in a contaminated environment for sortie type $i$ and which is defined by Equation (3).

The sortie degrade for the entire combat airbase for one TBM hit on a particular day is then

$$\mathrm{SD}^* = 1 - \frac{C^*}{D^*}. \tag{4}$$

4.7. **Sortie Degrade for Multiple Simultaneous TBM Hits.** The most common case of chemical attacks on combat airbases is when threat forces fire multiple TBMs at the combat airbase in an attempt to overcome the missile defense systems there. This is usually called a *raid* on the combat airbase. The sortie degrade can still be found in this case, if multiple TBM hits are treated as independent events.

For every node $i$ in the sortie generation network, let $p_i$ be the offset version of SSPC (as before) and let $n$ be the number of TBMs constituting the raid. Then the raid SSPC can be thought of as having at least one success occur in $n$ independent (Bernoulli) trials with probability of success $p_i$, and thus can be computed by

$$\sum_{j=1}^{n} \binom{n}{j} p_i^j q_i^{n-j} = 1 - (1-p_i)^n = 1 - q_i^n.$$

Hence, the expected sortie generation time in a contaminated environment (for a fixed sortie type) is now

$$D' = \sum_{i=1}^{N} [(1-q_i^n)\, d_i + q_i^n\, c_i] + \sum_{i=1}^{N-1} \beta_i t_i,$$

and the sortie degrade $\mathrm{SD}^*$ of Equation (4) can be computed as before.

4.8. **TBM Warning Alarm & Sortie Degrade.** Another issue that must be addressed in computing an overall combat airbase sortie degrade is the Air Force Counter-Chemical Warfare (C-CW) Concept of Operations (CONOP) degrade. The C-CW degrade encompasses a warning time of 30 minutes to alert base personnel of incoming missiles and a reconnaissance/assessment time of 30 minutes to allow for hazard teams to identify and mark any chemical contamination on the airbase

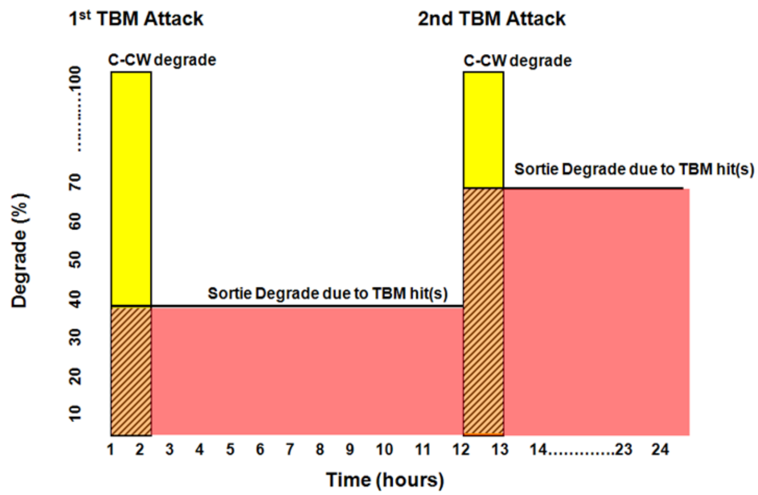


FIGURE 4. Effect of C-CW Degrade

and report it to the operations center. This equates to a 4.2 percent degrade to sortie generation for each attack the base incurs and is applied in addition to the overall sortie degrade.

Figure 4 illustrates that the entire combat airbase ceases operations (100 percent degrade) when a TBM attack is launched at the airbase followed by reconnaissance and reporting procedures for chemical contamination. The sortie degrade is then applied to sortie operations as the airbase resumes work in a contaminated environment. The process repeats itself as another TBM attack is launched at the combat airbase. Based on chemical agent persistency of 24 hours for VX nerve agent, the second attack raises the sortie degrade factor due to new levels of chemical agent falling onto earlier contamination.

4.9. **Weather Degrade.** Prior to the campaign analyst's applying the overall sortie degrade in JICM, the factor must be compared against the weather degrade.

JICM generates a weather degrade based on historical weather patterns. For study purposes, CAB A has a weather degrade of 50 percent on day 3 of the campaign and reduces the planned number of sorties from 67 to 34. The overall sortie degrade must now be compared to the weather degrade.

With an overall sortie degrade factor of 45 percent and a weather degrade factor of 50 percent, the campaign analyst must chose the weather degrade as the factor that reduces the number of sorties the most on day 3. This process is repeated for each day of the campaign and the degrade that most reduces the number of sorties is utilized in JICM.

## 5. CONCLUSION

We addressed a new methodology, built upon previous community efforts, to compute sortie degrade factors on combat airbases due to threat chemical TBM attacks. The new methodology utilizes an approach based on JMEM Weaponeering System SSPD, and incorporates combat airbase layouts (via satellite imagery), chemical hazard plumes, and various sortie types and capacities. The end product is a lookup table for use in JICM that contains a daily sortie degrade factor per combat airbase per day of the campaign.

The biggest contributors to the SSPD approach are weapon accuracy and chemical lethal areas. Obtaining true combat airbase sortie capacities from the Air Force will allow for a more realistic sortie degrade calculation. There is also room for this methodology to grow since it can incorporate new combat airbase layouts (sortie networks and nodes), additional munitions specifications, chemical agent fate modifications, and Air Force C-CW CONOP updates. It is recommended that this methodology be considered for use in the Reception, Staging, Onward Movement, and Integration (RSOI) process by generating degrades to the flow of soldiers and equipment due to chemical attacks on Aerial Ports of Debarkation (APODs) and Sea Ports of Debarkation (SPODs) operations.

## NOTES

[1]The Joint Technical Coordinating Group for Munitions Effectiveness (JTCF/ME) is the sole US DoD Agency responsible for the standardization of methodologies and data for evaluating and comparing weapons system performance against different targets. Its main product is a software package known as the Joint Munitions Effectiveness Manual (JMEM) Weaponeering System (JWS). JWS is currently used by all services and combatant commanders to estimate the effects of weapon systems against an extensive target list. The JWS model utilizes two specific methodologies to estimate the effectiveness of a weapon system on target: SSPD and Effective Fractional Damage (EFD).

[2]We note that for the sortie degrade calculation where the typical chemical plume was about 1 kilometer by 7 kilometers in size and the largest target was only a couple hundred meters in length, the size of the target in comparison to the lethal area (chemical plume) was not considered a factor in determining the probability of contamination.

[3]See Driels (2004), section 6.19 for a detailed discussion.

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## ACRONYM LIST

APOD — Aerial Port of Debarkation
ASMAA — Air to Surface Munitions Assembly Area
BAI — Battlefield Air Interdiction
C-CW — Counter-Chemical Warfare
CAA — Center for Army Analysis
CONOP — Concept of Operations
DEP — Deflection Error Probable
JICM — Joint Integrated Contingency Model
JMEM — Joint Munitions Effectiveness Manual
JWS — JMEM Weaponeering System
MOPP — Mission-Oriented Protective Posture
PK — Probability of Kill
REP — Range Error Probable
RSOI — Reception, Staging, Onward Movement, and Integration
SPOD — Sea Port of Debarkation
SSPC — Single Shot Probability of Contamination
SSPD — Single Shot Probability of Destruction
TBM — Theater Ballistic Missile
TTM — Task Time Multiplier
TTP — Tactics, Techniques, and Procedures
VLSTRACK — Vapor, Liquid, and Solid Tracking