Weather-Impact Decision Aids: Software to Help Plan Optimal Sensor and System Performance

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Weather can play a decisive role in military battles, in their planning, and in their execution. Weather-impact decision aids give the commander an edge by allowing both a determination of the optimum selection of weapon systems and a comparison with threat systems under current or forecast weather. This article describes two weather-tactical decision aids: the Integrated Weather Effects Decision Aid and the Target Acquisition Weapons Software.

Weather is ubiquitous; planning for it is an everyday occurrence, yet it still manages to foul up our plans. Recent military examples abound, such as dust clouds that grounded sorties in Operation Allied Force in Kosovo. To effectively execute missions, the military commander must be aware of the weather and its impact on his/her equipment, personnel, and operations. There are a number of weather-impact decision aids (WIDAs) that determine weather effects on mission-selected equipment and operations. Generally, these WIDAs may be broken into two subsets: rule-based and physics-based.

Rule-based WIDAs, such as the Army's Integrated Weather Effects Decision Aid (IWEDA) [1], are constructed using observed weather impacts that have been collected from field manuals, training centers and schools, and subject matter experts. IWEDA provides information (in the form of stoplight charts) concerning which weapon systems will work best under forecast weather conditions; no information is provided concerning target acquisition range.

Physics-based tactical decision aids (TDAs), such as the Tri-Service Target Acquisition Weapons Software (TAWS) [2], employ physics calculations that have their basis in theory and/or measurements. TAWS determines the probability of detecting a given target at a given range under existing or predicted weather conditions. Thus, physics-based systems produce results in terms of a performance metric that take on a continuum of values rather than the simpler stoplight results from the rule-based systems.

The IWEDA

IWEDA, a UNIX-based program written in Java, is a collection of rules with associated critical values for aiding the commander in selecting an appropriate platform, system, or sensor under given or forecast weather conditions. It provides qualitative weather impacts for platforms, weapon systems, and operations, including soldier performance.

Each system (Army, Air Force, Navy, and threat) has its list of relevant rules, which include red-amber-green (unfavorable-marginal-favorable) *critical value thresholds* for one or a combination of the environmental parameters that affect the system. Results are displayed via a matrix of impacts vs. time (see Figures 1 and 2) and map overlays (see Figure 3, page 18) for the region of interest. Environmental data for the region of interest is supplied primarily via the Army's Battlescale Forecast Model [2], developed for short-range forecasting. The environmental impact rules and critical values for the various systems have been

Figure 1: *IWEDA Weather Effect Matrices*

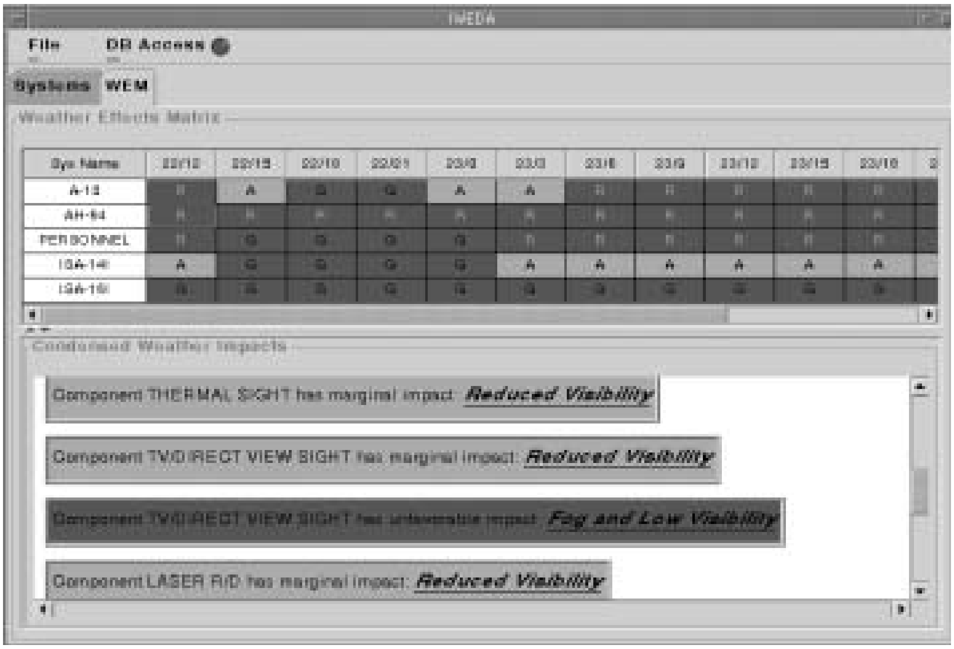

Figure 2: *IWEDA Full Impacts*

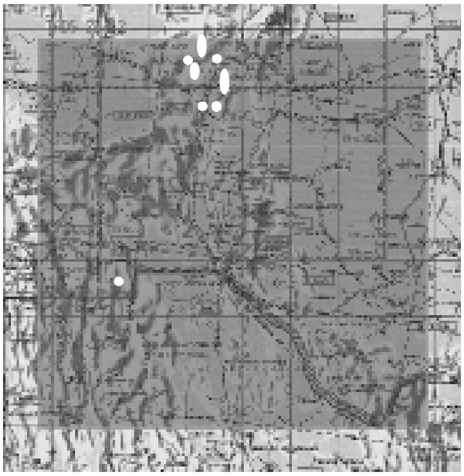

Figure 3: *IWEDA Map Overlay for AH-64 TADS TV/DVO*

validated through the Training and Doctrine Command's organizations, field manuals and the National Ground and Intelligence Center.

IWEDA is currently being fielded as part of the Army's Command, Control, Communications, Computers and Intelligence (C4I) tactical weather system, the Integrated Meteorological System. As a C4I tool, IWEDA does not dictate a course of action, but only informs the commander that there will be weather impacts on the force (friendly or threat).

IWEDA rules, which interact with the weather database to determine impacts on the selected system(s), are determined from system concepts and are embodied in a computer database that has been tied to *critical values*. The critical values are defined, in a meteorological sense, as those values of weather factors that can significantly reduce the effectiveness of, or prevent execution of, tactical operations and/or weapon systems.

An example of such a rule would be "usage of TOW2 is not recommended for visibilities less than three kilometers." In this example rule, a visibility of three kilometers (the critical value) has been coupled with a system (TOW2) resulting in a rule. We can further define this critical value, or range of values, as the point where the occurrence of a meteorological element causes a significant (moderate or severe) impact on a military operation, system, subsystem, or personnel.

In general, the rules are determined by operational usage (as embodied in the field manuals, etc.), whereas the critical values are determined by doctrine, safety, or engineering factors (people, modeling, or testing). Currently IWEDA stores information on 102 systems, 86 of which are friendly, 16 of which are threat-rated.

IWEDA Operational Usage

IWEDA is arranged in a fashion that presents systems, subsystems and components in a hierarchal fashion. A group of systems is called a mission; a system often contains one or more subsystems; the subsystems often have one or more components. The user has the option to define which systems belong to a mission and to delete optional subsystems and components from a system thereby allowing a determination of weather impacts from operations or missions at the highest level down to systems, subsystems, and components at the lowest level.

For missions, systems, subsystems, and components, the impacts over the forecast period are shown on weather effects matrices (WEMs, see Figure 1). The WEM is color-coded; for use with non-color printers, cells are annotated with R (red), A (amber), or G (green). Red areas indicate that operations are severely impacted: There is either a total or severe degradation or the operational limits or safety criteria have been exceeded. Amber indicates that operations are marginal and the operational capability is degraded, or there is a marginal degradation. Green indicates that there are no operational restrictions.

Based on requirements, users may query and view various levels of information: text impact statements or spatial distributions of impacts on a map overlay.

IWEDA Example

In the following example, a user-defined mission is created by selecting three friendly and two threat systems. Once the mission has been configured, the database is queried to determine the weather impacts on the systems, their subsystems, and components. Results are presented as a function of time and location.

To construct the example mission, the A-10, AH-64, personnel, SA-14, and SA-16 systems were selected from IWEDA's *friendly* and *threat* graphical user interfaces (GUI). Once these systems have been selected, IWEDA determines the weather impacts on the mission; results are presented to the user in the form of a WEM, as shown in Figure 1.

Initially, the lower half of the WEM is blank with the upper half showing the weather impacts as a function of system(s) and time. By performing a *right* click on any of the colored cells, such as the AH-64 for 22/12 (day/time), condensed impacts are shown in a scrollable window in the lower half of the WEM (impacts for the configured AH-64 system have been reproduced in Table 1). The WEM shows impacts on the AH-64 system as a function of time and general environmental conditions, but we do not know the full (detailed) impact or where the impact is occurring within the forecast area.

To determine the full impact statement and the location, a *left* mouse click is performed on the AH-64 cell for the selected day of the month and time, i.e., 22/12. This brings up the next screen (see Figure 2) that presents all of the selected AH-64 subsystems and components and their color-coded impacts.

As in the WEM GUI, initially only the top half of Figure 2 is presented to the user. To obtain further information, the user clicks on one of the colored blocks; in the example presented, the TV/direct view sight component of the Target Acquisition Designation Sight (TADS) has been interrogated. This results in a color-coded map overlay (Figure 3) showing where the TV/D is affected by the weather. The full impact statement, along with its source, can now be obtained by moving the cursor (shown as a white circle) and clicking upon a white area on the map (upper left of center).

The associated full impact statement then appears in the lower half of Figure 2, which in this case is "Any occurrence of fog or visibility <1.9 mi (3100m) significantly reduces the target and background contrast making target acquisition difficult." Contrast this with the condensed impact statement of "Fog and Low Visibility" shown in the WEM.

In summary, the colored cells in the WEM display the *worst-case* condition for the selected mission, during the *selected time*, for the *entire forecast region*. If the user wishes to know why a particular cell is red or amber,

Table 1: *Impacts for the AH-64 System for 22/12*

System AH-64 has marginal impact: High Pressure Altitude
Subsystem 30 MM MACHINE GUN has marginal impact: Low Visibility
Component THERMAL SIGHT has marginal impact: Reduced Visibility
Component TV/DIRECT VIEW SIGHT has marginal impact: Reduced Visibility
Component TV/DIRECT VIEW SIGHT has unfavorable impact: Fog and Low Visibility
Component Laser R/D has marginal impact: Reduced Visibility
Component Laser R/D has unfavorable impact: Low Visibility
Subsystem HELLFIRE has marginal impact: Icing Aloft
Subsystem GENERATOR has marginal impact: High Altitude
Component NIGHT VISION GOGGLES has unfavorable impact: Reduced Illumination

further information is available in impact statements, which explain why a particular cell exists. Detailed analysis for the impacted system or sensor can be obtained from the color-coded map.

The TAWS

TAWS [3], a GUI-based program running under the Windows operating system, is a Tri-Service program that includes Air Force, Army, and Navy sensors and targets. TAWS supports systems in three regions of the spectrum: visible (0.4 - 0.9 microns), laser (1.06 microns), and infrared (IR) (3-5 microns; 8-12 microns). It accepts current or forecast weather data to determine target detection range for selected sensors and targets. The commander uses this information for mission-planning purposes or to ascertain which sensors can see the furthest under the given weather conditions.

TAWS performs both illumination and performance prediction calculations (PPC). The PPC can be done for single or multiple locations during a mission. The illumination analysis involves the computation of solar and lunar ephemeris information for a specified location. A mission planner, for example, might be interested in an illumination analysis to determine the time of sunset for a particular mission date and location. For a single location, the PPC could be used to predict detection range for a particularly important target as a function of time, while a PPC for multiple locations along a mission route would be useful to a mission planner predicting detection ranges for a series of key locations as a function of time.

To determine the acquisition range to a given target a number of quantities need to be known: the target-to-background contrast, the atmospheric conditions, solar or lunar luminance, and sensor characteristics, all of which vary with spectral region. We discuss each of these in the following sections and provide an illustrative example at the end.

Target-to-Background Contrast

Contrast is defined as the ability of an observer to distinguish an object from its background; it degrades as the atmospheric path length increases. At visible wavelengths, where radiation scattering from atmospheric particulates is important, the mathematical formulation of the contrast is different than in the infrared (IR), where emission is the dominant process. Since TAWS computes contrast in both of these spectral regions, we present the following formulations.

Visual Contrast Model: The inherent, or zero range (usually defined as the target's position), contrast at visible wavelengths, C(0), is the difference between the target, I_t, and background, I_b, radiances, divided by the background radiance,

$$C(0) = [I_t(0) - I_b(0)]/I_b(0). \qquad (1)$$

We may express the apparent contrast at range *r* as

$$C(r) = \frac{C(0)}{1+[\, I_p(r)/I_b(0)][\, 1/T(r)]}, \qquad (2)$$

where $T(r)$ is the atmospheric transmission, and I_p is radiation scattered from atmospheric aerosols and gases into the line-of-sight. I_p is called the path radiance and may be thought of as atmospheric noise scattered into the sensor's field of view; it is not dependent upon the target.

In TAWS at visible wavelengths, the target and background radiances are determined using Hering and Johnson's Fast Atmospheric SCATtering model (FASCAT) [4], which calculates upwelling and downwelling radiance terms at specified heights in the atmosphere.

For designated sensor and target altitudes, the apparent contrast is calculated for slant paths, which may include an optional cloud layer. Objects in sunlight or shadow may be viewed against sky, cloud, or terrain backgrounds. The path radiance I_p, and the background radiance I_b, are determined by a multiple scattering calculation using the delta-Eddington approximation [5] in conjunction with the atmospheric model. The contrast is subsequently determined using equation (2).

For visible/near-IR scenarios, the target may be on the ground or elevated. An elevated target may be viewed with an upward or downward line-of-sight (LOS). Sky and cloud backgrounds are supported for the upward LOS; distant earth and low-lying cloud backgrounds are supported for the downward LOS.

Thermal Contrast Model: The inherent contrast at thermal wavelengths is defined as the target temperature minus the background temperature,

$$C(0) = [I_t(0) - I_b(0)] = \Delta T, \qquad (3)$$

where ΔT is the temperature difference between the target and background. Note that as the temperature increases, so will the inherent radiance, *I(0)*. Thus, the contrast in the IR is,

$$C(r) = C(0)\ T(r) = \Delta T\ T(r). \qquad (4)$$

In TAWS, C(0) is determined indirectly by the Multi-Service Electro-optic Signature model (MuSES) [6], which calculates the equilibrium background and target temperatures using antecedent illumination and weather data.

MuSES has two primary components: a thermal analyzer module and a signature model. Thermal analysis is the computation of physical temperature and heat rates that are obtained through energy balance on a node or isothermal element using a finite-difference numerical solution of the differential equations. The main output of a thermal model is physical temperatures and net heat rates that compare to empirical measurements of contact sensors.

The signature analysis is the computation of apparent temperature or radiance, which is composed of an emitted component that is a function of physical temperature and emissivity and a reflected component that is a function of irradiance from its surroundings and its reflectivity. In other words, the signature is what a sensor views and measures the radiance of a target, which is only partially dependent on its physical temperature. Thus, the signature model provides a link between the output of the thermal model and the desired output in signature analyses.

The basic heat source components considered by MuSES include longwave radiation, solar absorption, engine heating, engine compartment air, exhaust gas, track and wheel heating, and convection. Interreflections between diffuse surfaces are also taken into consideration. These various temperatures and effects are used to calculate ΔT.

Laser Contrast Model: The laser model does not compute contrast.

Atmospheric Information

To determine the loss of energy as radiation passes through the atmosphere requires knowledge of the atmospheric constituents (gases and aerosols) and its state (pressure, temperature, relative humidity, etc.). This loss of energy is expressed in the form of atmospheric transmission, which ranges in value from zero to one and is highly dependent upon the aerosol type present. This loss of energy can be represented by Beer's law for atmospheric transmission,

$$T(r) = e^{-(k_a + k_p + k_m)\, r}, \qquad (5)$$

where k_a, k_p, and k_m are the aerosol, precipitation, and molecular extinction coefficients, respectively. The molecular extinction coefficients are determined in TAWS by using a scaled down version of the low transmission atmospheric propagation code

Aerosol	Properties
Rural	Boundary layer background aerosol found in continental air masses.
Urban	Rural aerosol plus an added component representing soot-like aerosols that include particles produced in urban and industrial complexes.
Maritime	Characterizes aerosols that include sea-salt particles; the target area is more than a few kilometers inland.
Tropospheric	Characterizes aerosols found in very clean air masses and in the free atmosphere above the boundary layer.
Desert	Characterizes aerosols found in the boundary layer of desert, arid, or semi-arid climatic regions.
Navy Maritime	Describes aerosols found in the boundary layer of oceanic environments; includes wind speed dependence.
Advective Fog	Characterizes wet aerosols found in dense fogs, where visibility is less than 1 km.
Radiative Fog	Describes aerosol properties in less dense fogs, where visibility is 1 km or greater.
Camouflage Smokes	Characterizes white phosphorus, fog oil, and hexachloroethane smoke.
Battlefield Induced Contaminants (BIC)	A persistent pall of smoke and dust that sometimes covers areas where intense combat has occurred.

Table 2: *TAWS Aerosol Models*

LOWTRAN [7]. The aerosol extinction coefficients [8, 9] are read from pre-calculated internal tables.

TAWS contains 10 aerosol and two precipitation models that are used in various combinations by the IR, television/night vision goggles, and laser models to determine the appropriate aerosol and/or precipitation extinction coefficients. The aerosols describe the primary particulates of the air mass close to the surface at the location of interest. The naturally occurring aerosols include rural, urban, maritime, tropospheric, desert, advective fog, radiative fog, and Navy maritime. There are three types of camouflage smokes: white phosphorus, fog oil, and hexachloroethane. A 10th aerosol, in the form of battlefield induced contaminants, is available for situations where there is a persistent pall of smoke and dust raised by combat. Properties of the aerosol models are presented in Table 2. TAWS also contains rain and snow precipitation models.

TAWS allows a wide range of meteorological conditions, all of which may be selected by the user and some of which may be automatically input via the Air Force Weather Agency (AFWA) or the Navy Tactical Environmental Data Server (TEDS). These meteorological parameters include the following (those values noted with an asterisk may be downloaded from AFWA or TEDS): atmospheric dewpoint temperature*; sea surface temperature*; wind velocity/direction*; visibility*; precipitation type/rate; surface aerosol type; battlefield induced contaminants; high-, mid-, and low-level clouds*; and the boundary layer height.

Solar/Lunar Illumination

Illumination analysis in TAWS involves the computation of solar and lunar ephemeris data for a specified location and a series of dates or times. Solar/lunar ephemeris input information is derived from user-input time of day/time of year and latitude/longitude, in conjunction with the Solar-Lunar Almanac Code [10].

The solar/lunar ephemeris information is also computed and used for target acquisition analysis. In this case, in conjunction with variable cloud cover, the solar/lunar position is used to calculate target/background heating for the IR model and inherent target/background radiance for the visible model. The laser model does not use ephemeris information.

Sensor Information

Sensors are user-selected once the spectral region has been chosen. The relevant sensor curve is automatically retrieved from the sensor database.

Within TAWS, target detection range for Silicon TeleVision (TV), night vision goggles (NVG), and IR sensors is determined by using the Acquire sensor performance model [11]. Acquire predicts target detection and discrimination range performance for systems that image in the visible and infrared spectral bands. Ranges and probabilities predicted by the model represent the expected performance of an ensemble of trained military observers with respect to an average target having a specified signature and size. TAWS currently only supports detection ranges; other acquisition ranges are scheduled to be added in the near term.

TAWS supports two different classes of systems that employ laser designators operating at 1.06 microns: laser ranging and laser lock-on systems. Each of these has designator and receiver components. The airborne laser ranging systems measure the distance from the ranger system to the target by measuring the travel time of the laser pulse from the designator to the target and from the target to the receiver. The designator and receiver are physically collocated in the same hardware package for all ranging systems. For the laser lock-on weapons, the designator illuminates the target and the receiver receives the reflected beam. TAWS predicts the maximum effective range for either the designator or lock-on receiver.

Example

We present here a winter scenario using a T-80 Soviet main battle tank in exercised and off modes, against a snow background at IR wavelengths. The sensor and tank were aligned such that the sensor always had a frontal view of the tank; the sensor height was 10 feet. The date and location were fixed at 21 December, latitude 37° 32’ N, longitude 127° 00’ E (Seoul, S. Korea), respectively. The weather conditions were overcast and snowing with visibilities of three miles (light snow) and one mile (heavy snow) with a light breeze (~3m/s) from the west. The relative humidity and temperature, taken from a climatological database [12], as a function of local time are presented in Table 3.

The results of the model run are shown in Figure 4. The two vertical lines, determined using the illumination analysis capability of TAWS, indicate the sunrise and sunset times. As expected, the detection range is considerably larger when the visibility is higher; for given weather conditions the exercised tank is easier to detect relative to the tank in the off state.

Thermal crossover, defined as the time during the day when the thermal contrast is at a minimum and the polarity of the contrast reverses, generally occurs at mid-morning and late afternoon. For example, in early morning the background temperature may be greater than the target temperature. After thermal crossover, the target temperature may be greater than the background temperature. In the example, ther-

Table 3: *Input Relative Humidity (RH) (%) and Temperature (°C) as a Function of Time (HRS)*

Time	1800	2100	0000	0300	0600	0900	1200	1500	1800	2100	0000
Temp	1	-3	-3	-5	-5	0	0	1	1	-3	-3
RH	69	74	74	86	86	80	80	69	69	74	74

mal crossover occurs at approximately 0900 and 1700, accounting for the low detection range at those times. The commander/user can now optimize assets by choosing a time when detection range is maximized and by avoiding those times such as when thermal crossover occurs, when detection ranges are at a minimum.

Using this information in conjunction with weather forecast information (as opposed to static information used in this example) provides additional relevant information. For example, let us examine the "tank on" curves in Figure 4. If the weather conditions were predicted to change from heavy to light snow at 1200 local, the detection range would increase from approximately one and one-half kilometers to approximately four and one-half kilometers, providing the commander with an opportunity for increased detection. Such scenarios may also be used for friendly/threat comparisons to determine the delta in range due to differing systems.

Conclusions

IWEDA provides the commander with an easy-to-use and interpret tactical application that allows for near real-time evaluation of sensor employment options. Automating the environmental parameter retrieval by using a prognostic data set further enhances the application and allows for realistic planning based on evolving weather.

TAWS aids the warfighter in determining what sensor/weapon system will work best against a user-selected target under adverse weather conditions. TAWS accomplishes this by using accepted sensor performance and aerosol models coupled with proven techniques for determining atmospheric transmission and contrast. In addition to determination of acquisition ranges, TAWS may be used for mission planning and for determination of *deltas* between friendly and threat systems.

Taken together, these TDAs provide the commander a significant advantage for system selection under adverse weather conditions.◆

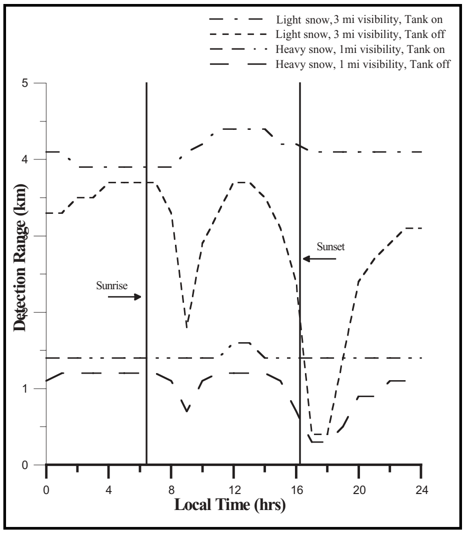

Figure 4: *Detection Range vs. Time*

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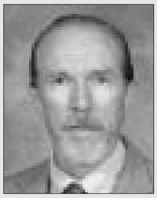

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