H13-15c
POTENTIAL USE OF TRANSPORT AND DISPERSION MODEL OUTPUT TO SUPPLEMENT ATP-45 HAZARD PREDICTION TEMPLATES

Nathan Platt and Leo Jones

Institute for Defense Analysis, Alexandria, Virginia, USA

Abstract: Allied Tactical Publication-45(C) is the current US and NATO command doctrine for Nuclear, Chemical and Biological (NBC) events. ATP-45 is designed to warn military populations of NBC hazard by providing area warning templates based on NBC messages. ATP-45 is designed to produce a single 2-hour hazard area template that accounts for wind speed fluctuations, but it does not take into account: a) time intervals of less than 2 hours and b) spatial and temporal variations in the wind field that could result in the incorrect orientation of the triangle template. Additionally, an abrupt discontinuity in the template from a circle to a triangle occurs as the wind speed passes through 10 km/hr. This abrupt change is unrealistic and can result in a significant under- or over-prediction of the hazard area. CT-Analyst, developed by the Naval Research Laboratory (NRL), is designed to provide near instantaneous hazard predictions resulting from large-scale chemical releases within a city. The CT-Analyst methodology is based on interpolation of pre-computed hazard area *nomografs*™. These nomografs are created by using a computational fluid dynamics (CFD) code (FAST3D-CT also developed and maintained by NRL) to produce highly-resolved urban transport and dispersion predictions. Our efforts have focused on comparisons of CT-Analyst hazard area predictions with the corresponding ATP-45 templates. In addition to using a single CT-Analyst hazard area corresponding to a single wind direction, we also considered allowing for wind direction variation by constructing CT-Analyst hazard areas corresponding to the union of predicted hazard areas for a certain wind angle sweep. We conclude that proper use of CT-Analyst or other transport and dispersion (T&D) models to produce real-time hazard area warnings: a) avoids the arbitrary discontinuity in the hazard area as the wind speed passes through any arbitrary threshold, b) could produce time-dependent hazard areas in less than 2-hour time intervals, c) consistently handles the risk, and d) can incorporate additional information if available. Notionally, we provide two suggestions on using CT-Analyst or other T&D models to supplement the ATP-45 hazard template: a) spatial evolution of the hazard area extent as the wind "sweep" angle is varied which loosely corresponds to the uncertainty associated with wind direction knowledge, and b) a time dependent hazard area for a preselected wind "sweep" angle and time-interval.

Key words: *ATP-45, CT-Analyst, hazard area prediction, real-time hazard area warning.*

BACKGROUND

Allied Tactical Publication-45(C) [ATP-45(C)] is the current U.S. and NATO command doctrine for Nuclear, Chemical and Biological (NBC) events. ATP-45 is designed to warn military populations of NBC hazard by providing area warning templates based on NBC messages. The warning area is constructed using a set of circles and triangles, the geometric parameters of which (e.g., length and type) depend on wind speed and direction, magnitude of the attack, and type of agent being released (e.g., neat or persistent). Common ATP-45 chemical templates for localized releases are depicted in Figure 1. This figure is reprinted from Heagy, *et al*., 2004a. ATP-45 is designed to produce a single 2-hour hazard area template that accounts for wind speed fluctuations, but it does not take into account: (1) time intervals of less than 2 hours and (2) spatial and temporal variations in the wind field that could result in incorrect orientation of the triangle template (e.g., for wind speeds exceeding 10 km/hr) as was demonstrated in an earlier Institute for Defense Analysis (IDA) study (Heagy, *et al.* 2004a, 2004b). In addition, an abrupt discontinuity in the template methodology causes the warning area shape to change from a circle to a triangle as the wind speed passes through 10 km/hr threshold. Such template phenomenon is unrealistic and might result in a significant under- or over-prediction of the hazard area – for instance, for a large non-persistent agent attack, the template's maximum downwind distance abruptly changes from 10 km to 15-50 km depending on atmospheric stability as the wind speed increases past the 10 km/hr threshold.

CT-Analyst (Boris, 2004), developed by the Naval Research Laboratory (NRL), is designed to provide near instantaneous hazard predictions resulting from large-scale chemical releases within a city. The CT-Analyst methodology is based on interpolation of pre-computed hazard area *nomografs*™. These nomografs are created by using a computational fluid dynamics (CFD) code (FAST3D-CT (J.P. Boris, 2002) also developed and maintained by NRL) to produce highly resolved urban transport and dispersion (T&D) predictions. IDA was tasked to examine CT-Analyst from the standpoint of model validity. By mutual agreement with our sponsor and NRL, we decided to evaluate CT-Analyst as a potential supplement to ATP-45 to support improved warning area characterization. Therefore, our efforts have focused on comparisons of CT-Analyst hazard area predictions with the corresponding ATP-45 templates. To help with our evaluations, NRL provided a specialized version of CT-Analyst capable of producing a sequence of binary outputs for a user-specified range of wind directions.

OUTLINE OF THE STUDY WITH A BRIEF SUMMARY OF CONCLUSIONS

CT-Analyst hazard area prediction is based on a 1-ton release of neutrally buoyant tracer that is meant to simulate the hazard area generated by a large scale chemical release. ATP-45 chemical template applicable to this CT-Analyst release is a non-persistent agent "MLRS, Missiles, Bombs, Unknown" template. To have a fair comparison with an ATP-45 2-hour hazard template for a wide range of wind speeds, CT-Analyst requires a very large area nomograf allowing hazard areas of 30-50 km in length. To create these nomografs at the high spatial resolution needed to capture urban effects (i.e., to resolve the wind flow around individual buildings) would require prohibitively long FAST3D-CT runs. The largest area high-resolution nomografs available for this study covered a square area of 10.8 km by 10.8 km with the hazard-area time evolution limited to 1-hour. Thus, we made an assumption to reduce the ATP-45 hazard area templates to *1-hour durations by reducing the downwind template distance by half.*

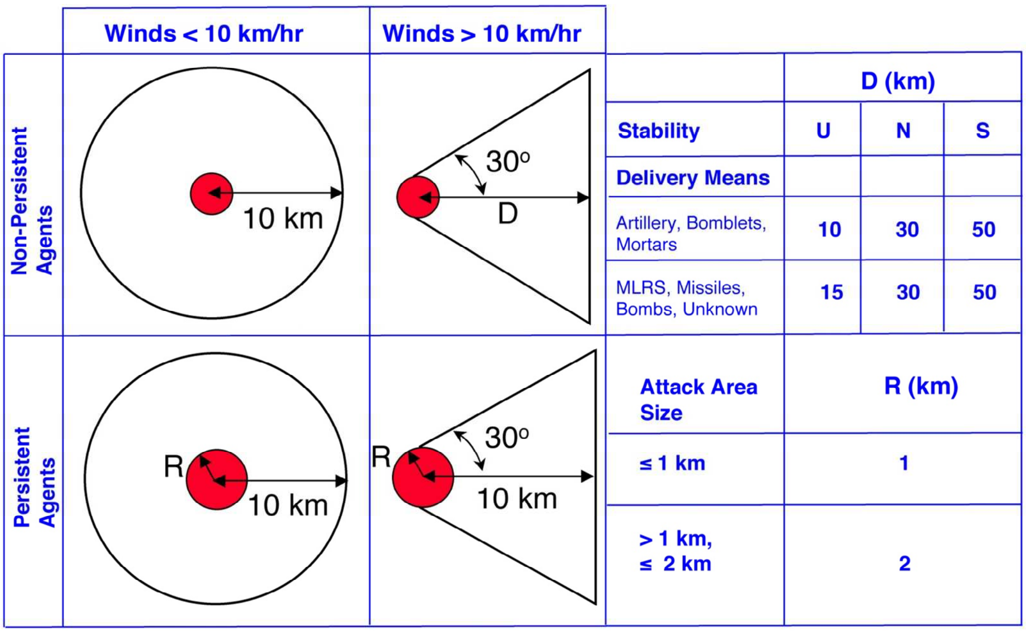


Figure 1. Common ATP-45 chemical 2-hour templates for localized releases. ATP-45 chemical template applicable to CT-Analyst release used in this study is a “Non-Persistent Agents” “MLRS, Missiles, Bombs, Unknown” template. Atmospheric stability category is used to define downwind extent of the hazard area triangle when wind speed is greater than 10 km/hr. This figure is reprinted from Heagy, et al, 2004a.

Our analysis proceeded along two lines. First, we selected a single location near the corner of the examined area that allowed for CT-Analyst hazard areas to fit within the region contained in the computed nomograf for a variety of wind speeds. The ATP-45 hazard-area template has an abrupt change from a circle to a triangle at 10 km/hr wind speed. The primary objective here is to compare ATP-45 and CT-Analyst hazard areas near that transition point. In addition to using a single CT-Analyst hazard area corresponding to a single wind direction, we also considered allowing for wind direction variation by constructing CT-Analyst hazard areas corresponding to the union of predicted hazard areas for a certain wind angle sweep as demonstrated in Figure 2. Second, seven additional locations were selected to determine a typical change in wind direction angle needed to make a computed union CT-Analyst hazard area to extend beyond the equal-size sides of the ATP-45 isosceles triangle (for wind speeds exceeding 10 km/hr). A two-dimensional user-oriented measure of effectiveness was used to determine this wind sweep angle for several different cases (Warner, *et al.*, 2004).

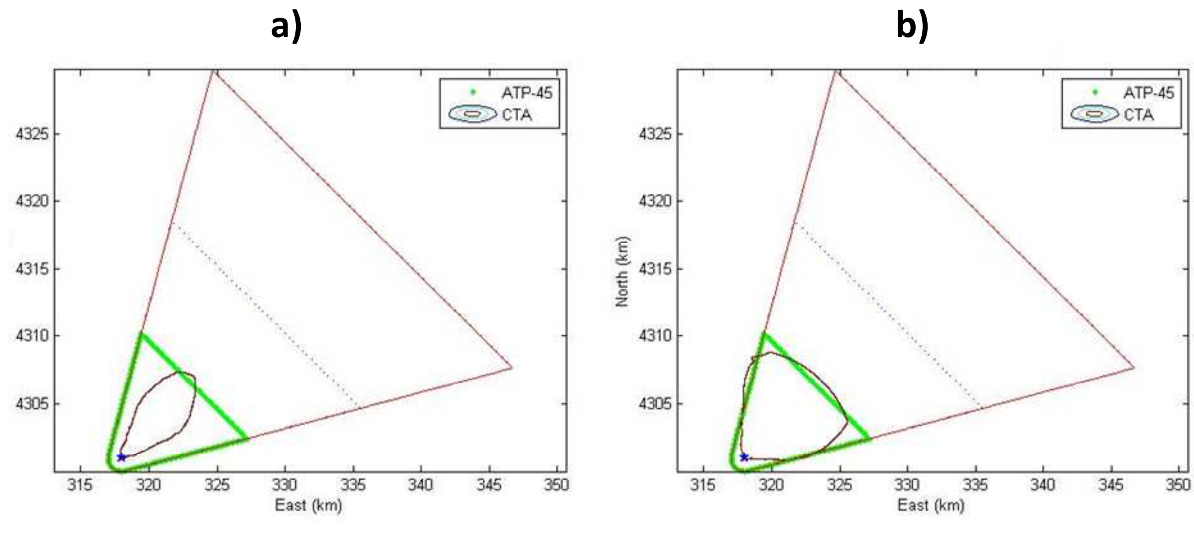


Figure 2. Comparison of CT-Analyst predicted hazard area for 10.1 km/hr wind speed. Triangles correspond to different ATP-45 hazard-area templates with downwind distance reduced in half to account for 1-hour hazard area evolution allowed in large-area nomograf supplied by NRL: inner green triangle corresponds to Unstable ATP-45 template, dashed line denotes Neutral ATP-45 template and outer brown triangle denotes Stable ATP-45 template. In graph a), CT-Analyst predicted hazard area is constructed from a single wind direction of 225 degrees. In graph b), CT-Analyst predicted hazard area is constructed from a union of individual hazard areas allowing wind direction to vary from 200 to 250 degrees (225 ±25 degrees) and is seen to extend just beyond the isosceles sides of the ATP-45 triangles.

The brief summary of the results is as follows:

For wind speed greater than 10 km/hr

1. The extent of the CT-Analyst hazard area lies beyond the Unstable ATP-45 triangle and becomes significant as the wind speed increases.
2. Neutral and Stable ATP-45 triangles envelop the single wind CT-Analyst hazard areas with the CT-Analyst hazard area being significantly smaller than the ATP 45 areas.
3. At certain ±Δ wind sweep angles, the union CT-Analyst hazard area extends beyond the sides of ATP-45 triangles. The calculated ±Δ wind direction angle when the union CT-Analyst hazard area extends just beyond the sides of ATP-45 triangles for wind speeds greater than 10 km/hr are 11, 9, 12, 10, 17, 18, and 10 degrees for the seven selected locations with a mean angle of 12 degrees and median angle of 11 degrees. Because of the turbulent and unpredictable behaviour of the atmosphere, these potential bounds on wind direction values are within realistic "error" bounds for measured wind, especially when using a representative single steady wind value to cover spatio-temporal evolution of the wind field over the evolution of the hazard area (e.g., 1-hour time interval used for the evolution of CT-Analyst hazard area).

For wind speed less than 10 km/hr

1. For some ranges of wind speeds above 5 km/hr, the CT-Analyst hazard area extends beyond the ATP-45 circle with the portion of the area that lies outside of ATP-45 circle becoming significant as the wind speed approaches the threshold wind speed of 10 km/hr.
2. Below some critical wind speed, the CT-Analyst hazard area lies completely within the ATP-45 circle.
3. Both single wind direction and a union CT-Analyst predicted areas are significantly smaller than the ATP-45 hazard area.

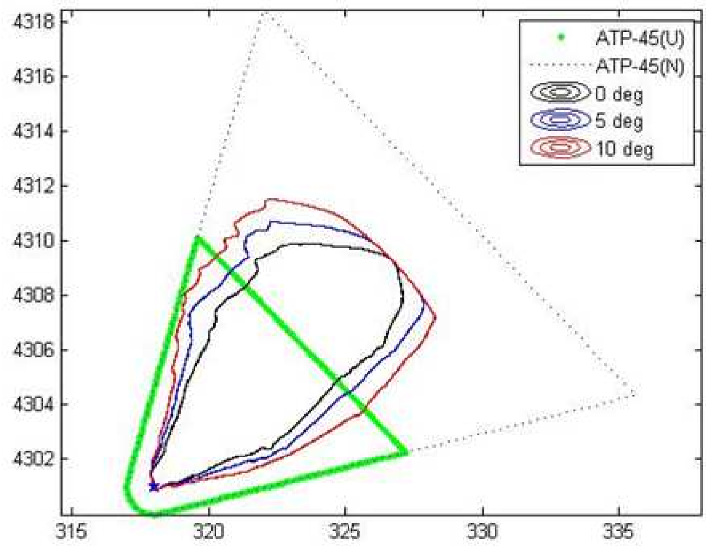
We conclude that the proper use of CT-Analyst or other T&D models to produce real-time hazard area warnings:

1. Does not have an arbitrary discontinuity in the hazard area at any wind speed (e.g., 10 km/hr) threshold.
2. Could produce time-dependent hazard areas in less than 2-hour time intervals.
3. Consistently handles the risk
4. Can incorporate additional information (e.g., complex, space and time dependent meteorology) if that information is available and could be utilized by the T&D model.

SUGGESTIONS ON USE OF CT-ANALYST OR OTHER T&D MODELS TO COMPUTE TIME-DEPENDENT HAZARD AREAS

As mentioned in the introduction, ATP-45 is designed to produce a single 2-hour hazard-area template that accounts for wind-speed fluctuations, but it does not take into account: (1) time intervals of less than 2 hours and (2) spatial and temporal variations in the wind field that could result in incorrect orientation of the triangle template (e.g., for wind speeds exceeding 10 km/hr). In addition, abrupt discontinuity in the template causes icons to change from a circle to a triangle as the wind speed passes through 10 km/hr threshold. Such template phenomenon is unrealistic and might result in a significant under- or over-prediction of the hazard area.

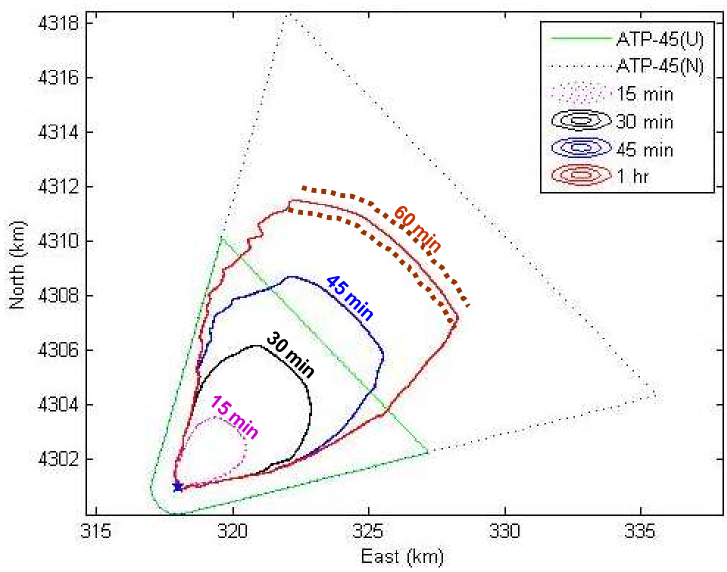
Notionally, we would like to provide two suggestions on using CT-Analyst or other T&D models to supplement the ATP-45 hazard template: (1) spatial evolution of hazard area extent as the wind sweep angle is varied, which loosely corresponds to the uncertainty associated with wind direction knowledge as depicted in Figure 3, and (2) a time dependent hazard area for a preselected wind sweep angle and time-interval as depicted in Figure 4.



- **Source location is at (318.0, 4301.0)**
- **Wind speed is 15 km/hr**
- **Mean wind direction is 225**
  - Used for ATP-45 triangle positioning
- **"Union" CT-Analyst hazard area is calculated in 1 increments for wind directions 225 ±5 and 225 ±10**

Wind direction fluctuations of ±5 and ±10 km/hr are purely notional
Actual values need further analysis and concurrence within CBD community
Because of limited spatial domain used in CT-Analyst nomograf, ATP-45 downwind extent is reduced in half

Figure 3. Notional demonstration of CT-Analyst use for real-time hazard prediction for fixed time period and varied wind direction fan designed to simulate uncertainties associated with assigning a single wind speed for a spatio-temporal domain of interest. Only two ATP-45 triangles are shown in this picture: the inner green triangle corresponds to an Unstable ATP-45 hazard-area template and the dotted outer triangle denotes a Neutral ATP-45 hazard-area template. The downwind extent of both of these triangles was reduced by half to coincide with the 1-hour maximum limit on CT-Analyst predicted hazard-area evolution. Three CT-Analyst hazard-area footprints are shown: the inner footprint corresponds to a single wind direction of 225 degrees, the middle footprint is constructed from a union of CT-Analyst footprints as wind directions are varied ±5 degrees around the mean wind direction of 225 degrees, and the outer footprint is constructed from a union of CT-Analyst footprints allowing the wind direction to vary ±10 degrees around the mean wind direction of 225 degrees.



- **Source location is at (318.0, 4301.0)**
- **Wind speed is 15 km/hr**
- **Mean wind direction is 225**
  - Used for ATP-45 triangle positioning
- **"Union" CT-Analyst hazard area is calculated in 1 increments for wind directions 225 ±10**
- **Potentially, one could vary wind speed by ±1 km/hr to account for errors in wind speed measurements**
  - Will result in two additional contours per time interval of interest
    - » Notionally denoted by brown dashed line on the leading edge of the hazard area in the picture

Time interval of 15 minutes, wind direction and speed fluctuations of ±10 and ±1 km/hr are purely notional
Actual values need further analysis and concurrence within CBD community
Because of limited spatial domain used in CT-Analyst nomograf, ATP-45 downwind extent is reduced in half

Figure 4. Notional demonstration of CT-Analyst use for temporal real-time hazard prediction for fixed wind direction fan designed to simulate uncertainties associated with assigning a single wind speed for a spatio-temporal domain. Only two ATP-45 triangles are shown in this picture: the inner green triangle corresponds to an Unstable ATP-45 hazard-area template and the dotted outer triangle denotes a Neutral ATP-45 hazard-area template. The downwind extent of both of these triangles was reduced by half to coincide with the 1-hour maximum limit on CT-Analyst predicted hazard-area evolution. A notional period of 15 minutes associated with hazard-area updates is assumed for this demonstration. The CT-Analyst predicted hazard area is calculated by taking a union of individual CT-Analyst footprints designed to simulate ±10 degree wind direction fluctuations around a mean wind of 225 degrees. The dotted lines around the leading edge of the 60-minute curve are meant to simulate ±1 km/hr wind speed fluctuations and are for illustration purposes only and did not involve any CT-Analyst calculations.

We conclude with the following:

1. We do not advocate that ATP-45 2-hour hazard area templates could or should be extended to include 1-hour hazard area templates. In fact, it would have been preferable to perform this study with high-resolution urban nomografs covering 2 hour hazard area evolution. Nevertheless, we believe that similar conclusions would have been reached.
2. Both wind direction fluctuation of ±5 and ±10 degrees used in the construction of Figure 2, and time intervals of 15 minutes, wind fluctuations of ±10 degrees, and wind speed variations of ±1 km used in the construction of Figure 3 are notional and are not being specifically advocated. If these suggestions on the use of a T&D model to supplement ATP-45 hazard area templates are to be contemplated, then the actual values to be used require further analyses and concurrence within the Chemical and Biological Defense (CBD) community.

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