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White Paper on Consequence Assessment of Transport of Hazardous Materials for PHMSA

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OAK RIDGE NATIONAL LABORATORY
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Computer Science & Mathematics Division
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ACRONYMS

AEGL	Acute Exposure Guideline
AFCC	Air Force Combat Climatology Center
DTRA	Defense Threat Reduction Agency
ESRL	Earth System Research Laboratory
ITRANS	Industrial Transportation
KML	Keyhole Markup Language
NOAA	National Oceanic and Atmospheric Administration
PHMSA	Pipeline and Hazardous Materials Safety Administration
SCIPUFF	Second-Order Closure Integrated Puff
TEEL	Temporary Emergency Exposure Limit
UDM	Urban Dispersion Model

LIST OF FIGURES

ABSTRACT

This document describes a proposed methodology for assessing the consequences of accidents during transport of hazardous materials in the form of compressed gases as liquids in the United States. A quantitative population effect risk metric for a transport plan in terms of population numbers and effects is described. Quantitative results provide the Pipeline and Hazardous Materials Safety Administration (PHMSA) a means for evaluating routes, times, and other plans for material movement. Hazard releases are modeled with a consequence assessment tool maintained by the Defense Threat Reduction Agency (DTRA) that uses the Second-Order Closure Integrated Puff (SCIPUFF) atmospheric transport and dispersion model. LandScan™ 2016 USA Day and Night distributions are used for population data.

1. BACKGROUND

Should an accident occur during transport of compressed gases as liquids via rail or road resulting in release of hazardous chemicals, the risk to nearby population can be significant. This risk to population posed by material transport can be quantified as a population effect risk metric and evaluated to determine preferable or even optimal routes and times for such transport. The risk metric can be the basis for an objective function used in choosing optimal transport plans. Further, an assessment of important transportation routes will provide the Pipeline and Hazardous Materials Safety Administration (PHMSA) a quantitative basis for comparing routes and associated risks.

2. SOLUTION

The Defense Threat Reduction Agency (DTRA) has a long history of development and enhancement of models and tools for assessing releases of hazardous materials. At the heart of these tools is the Second-Order Closure Integrated Puff (SCIPUFF) atmospheric transport and dispersion model. Among the many DTRA hazard models is Industrial Transportation (ITRANS), which can characterize the releases resulting from accidents and failures involving rail and road transportation vehicles. These releases are then modeled with SCIPUFF to determine doses, depositions, and their human effects. Moreover, DTRA's Urban Dispersion Model (UDM) accounts for urban canopies in atmospheric transport.

Although an exhaustive analysis of every active and potential transportation route is intractable, important routes involving major population centers can be analyzed with much benefit. We propose analyzing the risks to population by:

- Identifying a limited number of important routes,
- Characterizing the routes by choosing representative locations or points along the routes,
- Characterizing weather and meteorological conditions,
- Defining representative accident scenarios,
- Executing tools and models, and
- Calculating the quantitative risk metric for scenarios and ensembles of weather conditions.

2.1 IDENTIFYING ROUTES

Analysis begins with identification of important rail (and optionally road) transportation routes involving major urban centers for which hazards will be modelled. Urban transport and dispersion are applied in metropolitan areas.[1] The number of routes selected is constrained only by the effort and schedule allocated for the analysis. (Candidate metropolitan areas would certainly include Houston and Phoenix and any others identified by PHMSA as high priority.)

2.2 CHARACTERIZING ROUTES

Routes are represented by choosing points along the route as potential accident locations. The distance between points along the route must be chosen carefully. One alternative is a fixed distance between points, and with infinite computing resources a small distance could be applied to capture all potential variations in conditions along the route. Practically, population in the area is a useful basis for determining the granularity needed. Whereas a relatively short distance between points should be used near or in a population center, the distance can be greater in rural areas with little nearby population. In addition, an importance factor or probability of occurrence can be applied to individual locations, but a reasonable default assumption is uniform importance of each location. The number of locations used to represent a route is also subject to the scope of effort and computing resources available, as well as the total number of routes to be analyzed.

2.3 CHARACTERIZING WEATHER AND METEOROLOGY

The most important inputs to any atmospheric transport and dispersion calculation are weather and meteorology. Given the nature of transportation accidents, surface observations are particularly important. Observation data available from the Earth System Research Laboratory (ESRL) of the National Oceanic and Atmospheric Administration (NOAA) will be used to characterize surface conditions in a wind rose, with the probability of occurrence of each wind direction and speed applied as a weighting factor as shown in Equation 1. Observation data covering a time span of at least one year will capture seasonal variations. This method of applying wind rose probabilities as risk assessment factors has been used successfully in prior work. [2]

2.4 DEFINING ACCIDENT SCENARIOS

One or more representative accident scenarios must be defined. Refer to a previous release modeling report for an example of the kinds of industrial transport scenarios envisioned. [3]

2.5 EXECUTING TOOLS AND MODELS

Models can be executed in batch (not interactive) mode to calculate the effects of many scenarios in succession, and multiple instances of each model can be run simultaneously to reduce the wall clock time required to complete all scenarios in an ensemble.

2.6 CALCULATING THE METRIC

The output of the transport and dispersion models include depositions and doses which are applied to qualitative exposure levels. Most chemicals are evaluated in terms of qualitative Acute Exposure Guidelines (AEGL), as well as casualty and mortality. AEGL levels are:

- AEGL-3 Death Possible
- AEGL-2 Injury Possible
- AEGL-1 Threshold

[1] DTRA has building footprint data for most major urban centers in the continental United States.

- Area of Concern

Mortality and casualty levels are:

- Mean Probability of Mortality (50%)
- Mean Probability of Casualty (50%)
- Mean Probability of Casualty (10%)
- Area of Concern (10% Pc)

In both cases Area of Concern in the model results accounts for uncertainty in climatology for a worst-case assessment of potential effects. Refer to Figure 1. These qualitative levels can be made quantitative by assigning a weighting factor to each level which is in turn applied to population counts. Note the chemical concentrations and doses from which qualitative levels are determined could also be used as the quantitative value, but the qualitative levels provided a consistent, comparative measure across various chemicals and materials. Thus, subjectively assigned weights associated with qualitative levels are preferred.

2.6.1 Scenario Population Effect

Summing the products of exposure level weights and population counts yields a quantitative number representing the population effect for a scenario:

$$S = \frac{\sum_{k=1}^{n} l_k p_k}{\sum_{k=1}^{n} l_k} \qquad (1)$$

where

S	is the scenario population effect value
l_k	is the weight for exposure level *k*
p_k	is the count of population affected at exposure level *k*
n	is the number of exposure levels

Exposure level weights are largely subjective values. Given the results illustrated in Figure 1, Table 1 and Table 2 show scenario population effects for example level weights.

Effect Level	Assigned Weight	Population	Metric Term
AEGL-1	1.0	11,799	842.79
AEGL-2	3.0	7,384	1582.29
AEGL-3	10.0	3,682	2630.00
		Population Effect	**5055.07**

Table 1. Example AEGL Population Effect

Effect Level	Assigned Weight	Population	Metric Term
10% Casuality	1.0	689	22.23

50% Casuality	5.0	225	36.29
50% Mortality	25.0	64	51.61
		Population Effect	**110.13**

Table 2. Example Casuality/Mortality Population Effect

2.6.2 Ensemble Risk Metric

For an individual route location/point, an ensemble of scenarios is created to model the event against various weather and meteorological conditions. Each weather condition has an associated probability of occurrence, with all condition probabilities summing to one. This probability is a weighting factor applied to the population effect resulting from the scenario model with those weather conditions. Collectively, the sum of the products of the weights and population effects for each scenario is the risk metric for the ensemble:

$$E = \sum_{i=1}^{n} w_i S_i \qquad (2)$$

$$1 = \sum_{i=1}^{n} w_i \qquad (3)$$

where

- E is the risk metric for the scenario ensemble,
- w_i is the probability for weather condition *i*,
- S_i is the scenario population effect for weather condition *i* (refer to Equation 1),
- n is the number of weather conditions.

Further, one can use historical or forecast weather for a route to compare alternative seasons or specific times for execution of that route. For example, one might determine the preference of a morning versus evening departure on a day for which a weather forecast is available.

2.6.3 Route Risk Metric

The ensemble risk metric is calculated for each point along a route, with the sum yielding the risk value for the route and weather conditions used for each scenario.

$$R = \frac{\sum_{j=1}^{n} p_j E_j}{\sum_{j=1}^{n} p_j} \qquad (4)$$

where

- R is the risk metric for the route,
- E_j is the scenario ensemble risk metric at route point *j* (Refer to Equation 2),
- p_j is the probability or weighting factor for point *j*,
- n is the number of points used for the route

To compare results for one route against another, some sort of normalization is necessary. Perhaps the

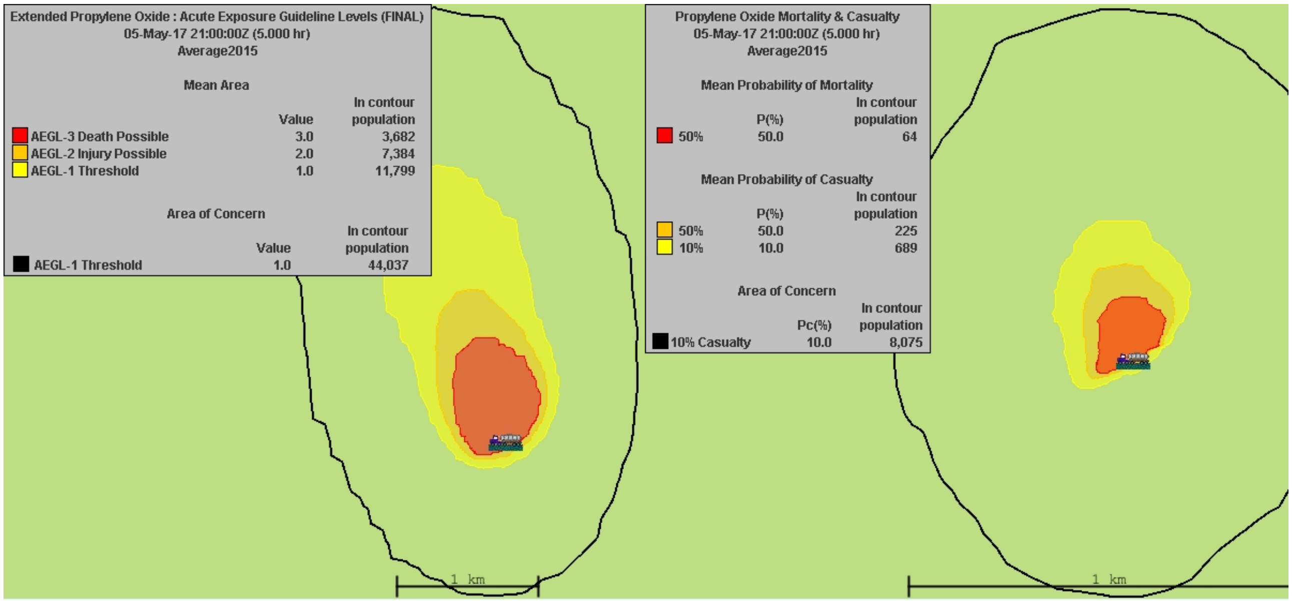

Figure 1. Effects Contours

simplest basis for normalization is distance. Clearly, a longer route would pose more risk than a shorter one given equivalent population in the nearby regions. One approach for distance-based inter-route comparison is to specify a fixed distance between points along both routes. Alternatively, the distance between points can used as an additional factor applied to the ensemble risk metric for each point. Distance for a point is best calculated using the midpoints between previous and next points. Equation 4 is modified as follows:

$$R = \frac{\sum_{j=1}^{n} d_j p_j E_j}{\sum_{j=1}^{n} p_j} \tag{5}$$

$$d_j = \frac{D(j,j+1)}{2}, j = 1 \tag{6}$$

$$d_j = \frac{D(j-1,j) + D(j,j+1)}{2}, 1 < j < 1 \tag{7}$$

$$d_j = \frac{D(j-1,j)}{2}, j = n \tag{8}$$

where

d_j	is the distance represented by point *j*,
D(*a*,*b*)	is the distance from point *a* to point *b*.

2.7 ASSESSMENT AND ANALYSIS TOOL

In addition to analysis products resulting from application of the proposed method, it is also possible to create a user tool for performing analyses on demand. A Web-based and/or desktop application providing all the capabilities of the methodology as well as generation of outputs and visualizations could prove useful to PHMSA analysts. This would require that PHMSA personnel request hazard and consequence assessment models from DTRA.

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