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INTEGRATION STUDY OF PROSPECTIVE HAZARDS MODELS FOR THE ENHANCEMENT OF A VIRTUAL RANGE SIMULATION MODEL

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ABSTRACT

This paper describes our progresses toward enhancing a Virtual Range (VR) for space launch modeling capability. The VR discussed in this paper is a range safety simulation environment. It is capable of determining the expectation of casualties (E_C) resulting from the toxic effects of gas dispersion caused by a failed space launch and subsequent explosion (accidental or instructed) of a spacecraft (the Space Shuttle in this instance) shortly after liftoff. In addition to the above, we are currently rendering the VR capable of also determining the E_C resulting from falling debris and blast overpressure propagation, which are the others two major hazards resulting from a spacecraft explosion. We also investigate two data fusion approaches to estimate the E_C resulting from the combined effects of the three hazards mentioned above, as their effects may not necessarily be independent of each other.

1 INTRODUCTION

Operating a spaceport such as NASA's Kennedy Space Center (KSC) is a complex task. It involves addressing a number of safety issues, such as the safety of (1) the public on the ground, (2) the astronauts, (3) the workforce and surrounding infrastructure, and (4) airborne aircraft and seafaring ships in the vicinity of the spaceport. To address the above, our effort consisted of investigating the integration of dispersion, debris, and blast models as follows. First, we introduce the VR and describe how it currently operates with a single prospective hazard model, CALPUFF, a multipuff, multiple sources gas dispersion model. We then present a hybrid approach to modeling blast effects resulting from an explosion shortly after liftoff by combining blast propagation theory and Blast/FX, a blast modeling tool with limited capability (developed by the FAA and Northrop Grumman), which is based on finite element analysis. Using the real coordinates of debris recovered from the Columbia Space Shuttle accident, we illustrate a methodology aimed at overcoming the issues related to the development of a debris layer. This paper then concludes with a discussion on our preliminary thoughts on the realm of data fusion for better assessment of the combined effect of the three prospective hazards (gas, debris, and blast) resulting from a spacecraft accident.

2 THE VIRTUAL RANGE (VR) SIMULATION MODEL

The VR, shown in Figure 1, is an environment that seamlessly integrates several models to improve complex systems visualization. It combines models of vehicle trajectory with estimates of the probability of failure of a Shuttle launch through the different stages from liftoff until separation of the solid rocket boosters, which occurs approximately 2 minutes after liftoff. A mishap is simulated using Monte Carlo simulation, which works by generating random numbers based on the probability of occurrence of certain events (in our case the events refer to those causes which may result in the loss of a vehicle). The probability of each major event was determined in previous work (Sepúlveda et al. 2004). The main advantage of this complex, non-linear configuration of systems is that it allows for an easier study and visualization of systems interaction properties over the traditional approach of decomposition (Sepúlveda et al. 2004).

In the future, spaceport authorities will be able to use the VR output to estimate the population at risk to help plan which areas to evacuate, determine the resources required to provide aid and comfort, and to mitigate damages in case of a disaster. However, in its present configuration, the VR can only determine the expectation of casualties

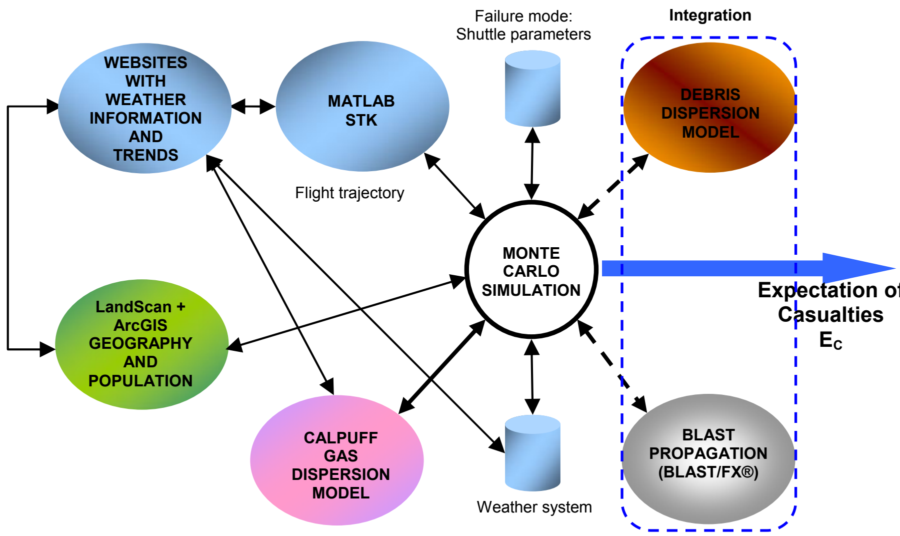

Figure 1: Individual Launch Support Components Integrated into a Virtual Range System Architecture

(E_C) resulting from the toxic effects of the gas dispersion from a Space Shuttle launch. The current VR does not account for the effects of blast and debris fragmentation generated during a failed launch.

2.1 Toxicity Model

Using knowledge of the initial amount and type of propellants for the vehicle and the fuel consumption rate, the VR calculates the amount of pollutants released at a specific point in the trajectory where an accident is simulated to occur. This information is an input to CALPUFF, a gas dispersion model. Other inputs needed by CALPUFF include the weather conditions such as wind and humidity conditions at the moment of the accident (Sepulveda et al. 2004).

The CALPUFF modeling system was developed by Sigma Research Corporation – now a part of Earth Tech, Inc. – as part of a study to design and develop a generalized non-steady-state air quality modeling system for regulatory use. Its is a very complex system composed of three main components: (1) CALMET, a diagnostic 3-dimensional meteorological model, (2) CALPUFF, an air quality dispersion model, and (3) CALPOST, a post processing package. The system is also capable of interfacing with standard, routinely-available, meteorological, and geophysical datasets.

Once a disaster has been simulated, CALMET is given the simulated date/time where the weather conditions meet the Launch Weather Criteria. The weather data for that date becomes the input to CALPUFF. After processing the amount of pollutant released in the air at a given location under the given weather conditions, CALPUFF determines the resulting contaminate concentrations. Using CALPOST, this information is entered as a layer which can be displayed on an ArcMap over a map of Florida. In Figure 2 the highlighted region is the area where the concentration of the pollutant exceeds a critical expectation of casualty value for GO/NOGO launch decisions at KSC.

The LandScan population layer (from Figure 1) is then accessed, which allow Spatial Analyst (an ArcView tool) to determine the number of people living in that area. With enough runs, an average and a confidence interval for the expectation of casualties due to gas releases is determined.

3 BLAST LAYER

Among all the prospective hazards resulting from an explosion, those caused by blast overpressure waves are often the most destructive. Our objective here was to validate a hybrid approach to predict blast hazards by simulating an explosion of the Space Shuttle ten seconds after liftoff from launch pad LC-39A at KSC. The hybrid approach was necessary to overcome the limited capability of Blast/FX, the blast modeling software at hand.

3.1 Blast/FX

Blast/FX was developed by Northrop Grumman Mission Systems to determine the effects of explosives against facilities and the people in those facilities. It is based on the TNT equivalency method of blast overpressure prediction. Although the software has some limitations, we determined that some of them could be overcome for the purpose of our study.

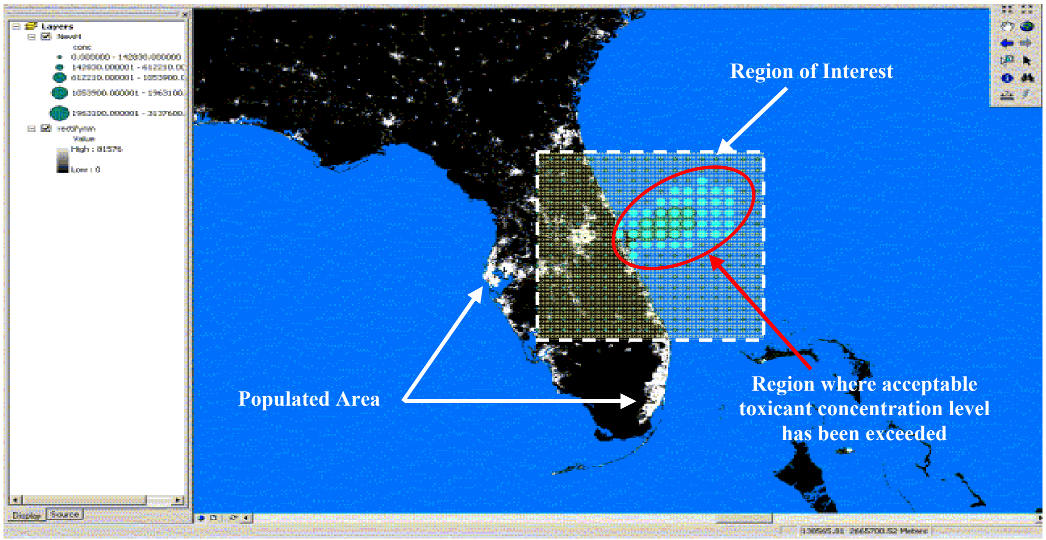

Figure 2: CALPUFF Output Displayed on ArcGIS. of Distribution of Toxicant Concentration Levels

3.2 The Scenario

The scenario involved 283 people and three locations at KSC:

1. The launch pad (LC-39A), which was selected as the center of the explosion 10 seconds after the NASA Shuttle was launched
2. The Launch Control Center (LCC), where we arbitrarily placed 179 people
3. The Press Site, where we placed 111 journalists and photographers.

Figure 3 is an illustration of the press site. The 16,000 sq-ft building was modeled with the following properties: a concrete floor, S15X50 steel columns and beams (AISC), a concrete wall on the back of the building and a ceiling of 12 ft. We assumed that 25% of people were located outside the building. Figure 4 is an aerial view of the three locations under study. The LCC is situated at 5,500 meters from LC-39A while the Press Site is slightly closer at 4,800 meters. We selected the LCC and the Press Site because they are heavily populated during a launch operation. From the space shuttle propellant consumption rate, we calculated the remaining propellant mass at different times during the launch. We next converted them to an equivalent TNT mass. The results obtained are shown in Table 1.

3.3 Methodology

As mentioned earlier, a hybrid approach was necessary to overcome some of the deficiencies of Blast/FX. These Blast/FX limitations include:

- The explosive should be less than 45,400 kg of equivalent TNT mass.
- The maximum area to perform the simulation should be a square with a side length 600 meters (we have distances greater than 5,000 meters).

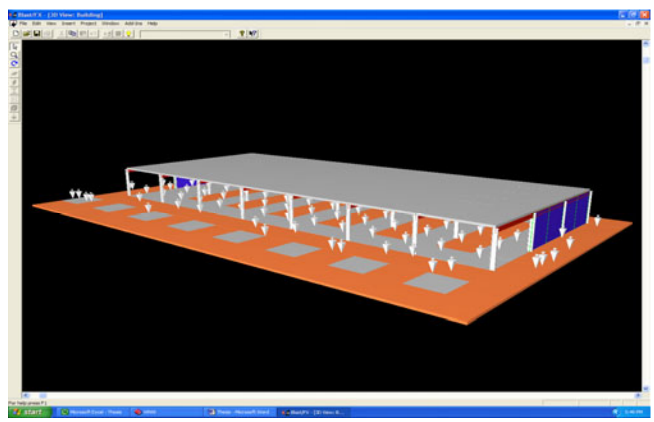

Figure 3: Front of the Press Site

Table 1: Rate Consumption and TNT Equivalent

Time (s)	Mass of remaining liquid propellant (kg)	Propulsion system	Mass of remaining solid propellant (kg)	Total mass of TNT equivalent (kg)
0	730,000	SRB	1,008,000	1,320,564
1	728,596	SRB	998,000	1,307,484
…	…	…	…	…
…	…	…	…	…
…	…	…	…	…
9	717,365	SRB	918,000	1,202,844
10	715,962	SRB	908,000	1,189,764

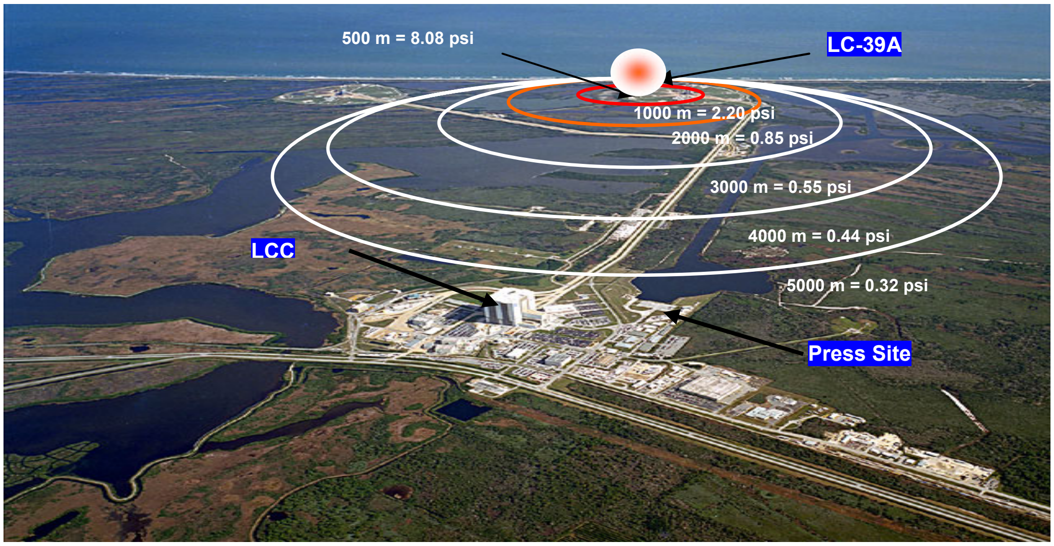

Figure 4: Blast Wave Overpressure Resulting from a Simulated Explosion Ten Seconds after Liftoff

Our approach (Figure 5) was to use Blast/FX to simulate short distance blast effects (from 100 m to 500 m in 100 m increments, from the LCC or the press site) for a fuel having an equivalent TNT mass of less than 45,500 kg. These distances would normally correspond to an accident occurring while the space shuttle is being ferried to its launch pad. We considered three masses: 45,500 kg, 22,700 kg and 11,350 kg, though the equivalent TNT mass of the shuttle at that moment is actually much higher.

The Hopkinson-Cranz Scaling Law was used to estimate the same effects for longer distances from LC-39A (from 500 m up to 5,500 m in 1,000 m increments, as shown in Figure 5) and using the actual amount of Space Shuttle fuel (Table 1). The law states that self-similar blast waves are produced at identical scaled distances "when two explosive charges of similar geometry and of the same explosive, but of different sizes, are detonated in the same atmosphere"(Krauthammer 1999).

3.4 Results

The results indicate that if an explosion were to occur at the launch pad, the LCC and the press site would not suffer significant damage from the blast overpressure phenomenon and the people in those facilities would not be injured. These results were rather expected as one can easily imagine that similar studies were performed during the conceptualization of KSC. On the other hand, an explosion in close proximity (particularly 100 m) would result in a partial or total destruction of these facilities.

The original idea was to develop, given those outputs, a blast layer on ArcMap, as it is currently done with the gas dispersion model. This proved very difficult given the very high level of resolution required to display this information (Gas can disperse over several kilometers as it accounts for wind effects, making it possible to represent in ArcView. The overpressure distribution, however, covers only a few thousands meters at most.). However, this might be overcome by using the methodology used to develop the debris layer which we describe in the next section

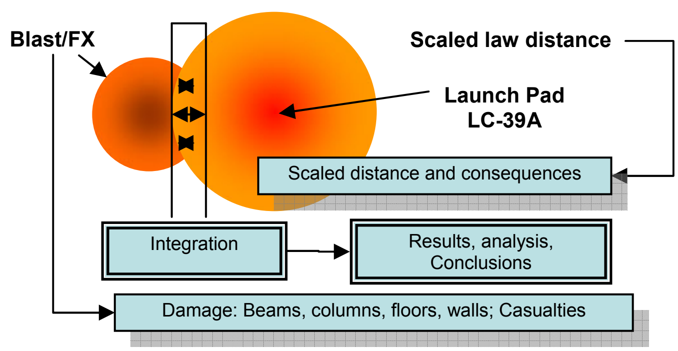

Figure 5: Blast/FX and Scaled Law Hybrid Approach

4 DEBRIS LAYER

4.1 Background on Debris Dispersion

A debris model is a mathematical simulation of a debris cloud which generates a probabilistic dispersion for the impact location of each piece of debris (CAIB Report 2003). In an explosion of a space vehicle, thousands of fragments of different shapes and sizes may be generated. NASA currently uses the Common Real Time Debris Footprint (CRTF), a state of the art debris dispersion model. The impact location of debris is influenced by uncertainties such as wind direction, perturbations in the initial velocity vector of the debris, and the debris aerodynamic coefficients of lift and drag (or ballistic coefficient). Any object in motion in a fluid experiences a drag force defined as

$$F_D = \frac{1}{2} C_D A \rho V^2$$

where F_D is the drag force, C_D the coefficient of drag of the object, A the exposed surface area of the object, and V its velocity.

4.2 Debris Layer

Generating an ArcMap debris layer is a necessary step the VR will have to perform not only to guide spaceport authorities toward the most affected areas, but also to determine the expected number of casualties in each of those areas.

As we did not have a debris model available at the time, we used the database created from the debris recovered from the Columbia accident to develop an ArcMap layer (we assumed the accident has already taken place, and we were concerned with visualizing the debris on the same map scale used by the gas dispersion model).

The VR works on a GIS platform, using a raster image of the U.S. This image comes from Oak Ridge National Laboratory (LandScan 2001 – Figure 1) and represents a population estimation associated with a given database. Compared to older versions, this image has the same resolution (1 km.), however it enhances state and county limits.

One of the major limitations of these types of images is related to geo-referencing. Therefore, as ArcMap already accepts all types of images, our main objective was to maintain a proportional relationship between terrain and what is actually represented on the screen, and furthermore, to allow for the inclusion of coordinates.

4.2.1 Geo-referencing

The LandScan image used in the VR was added to our active data frame in ArcMap. The spatial data set in the target coordinate system was found at the commercial website <http://www.geographynetwork.com>. This spatial data set provided a known coordinate system, WGS 84 (GCS_North_American_1983, as cited in the source properties of the layer), and is based on the 1983 North American Datum (D_North_american_1983, as cited in the source properties).

To geo-reference the image from the raster data set to a real world coordinate system, locations of various recognizable features had to be identified. These features represented control points which were given by the control layer found in the website above. Through the geo-referencing toolbar provided inside ArcMap, links were added between the control and the raster layer. The more links added, the more accurate the transformation. At a minimum, three links are needed for a first-order transformation, while six to ten links are needed for second-order and third-order transformations, respectively. Figure 6 shows the raster geo-referenced to the coordinates of the control layer.

4.2.2 Resolution and Overlaying

Adding a layer had the significant advantage of overcoming the poor resolution obtained when zooming the raster image. The features, which here are small pieces of debris, persist even when we zoom the image because of the vector data set we introduced.

4.2.3 The Data

Validating the approach described above would have been very difficult (if not impossible) if we did not have one of the (if not the only) debris databases from a Shuttle vehicle accident. On February 1st, 2003 the loss of the NASA Space Shuttle Columbia led to the largest debris search in US history. The search resulted in a database of more than 80,000 pieces of orbital debris weighing a total of more than 84,900 lb (CAIB Report 2003). The database contains information provided by both the Federal Emergency Management Agency's (FEMA) Shuttle Interagency Debris Database (SIDD) and the Environmental Protection Agency (EPA) database.

However the complete database could not readily be used for our exercise. We concentrated our effort on 7,147 of the 15,470 debris pieces recorded that had at least two of their dimensions and the geographic coordinates of where they were found. To display these fragments as a layer, we first standardized the geographic coordinates format in which they were recorded then converted these values into X, Y coordinates for ArcMap. The resulting ArcMap output is shown in Figure 7.

In this section we described our effort in developing a debris layer on the same raster image used by CALPUFF for gas dispersion visualization purposes. This tells us that once a debris model becomes available, the VR will be capable of generating a debris layer as originally intended. The lessons learned in this study should also help in the development of a layer for the blast overpressure generated at the moment of an explosion as discussed in section 3.

5 DATA FUSION TECHNIQUES

As illustrated back in Figure 1, the three prospective hazard models considered in the eventual explosion of a spacecraft are linked to a Monte Carlo simulation. Therefore, after multiple runs, a probability density function for each of these hazards can be generated for any geographic location of interest. We investigated the use of two data fu-

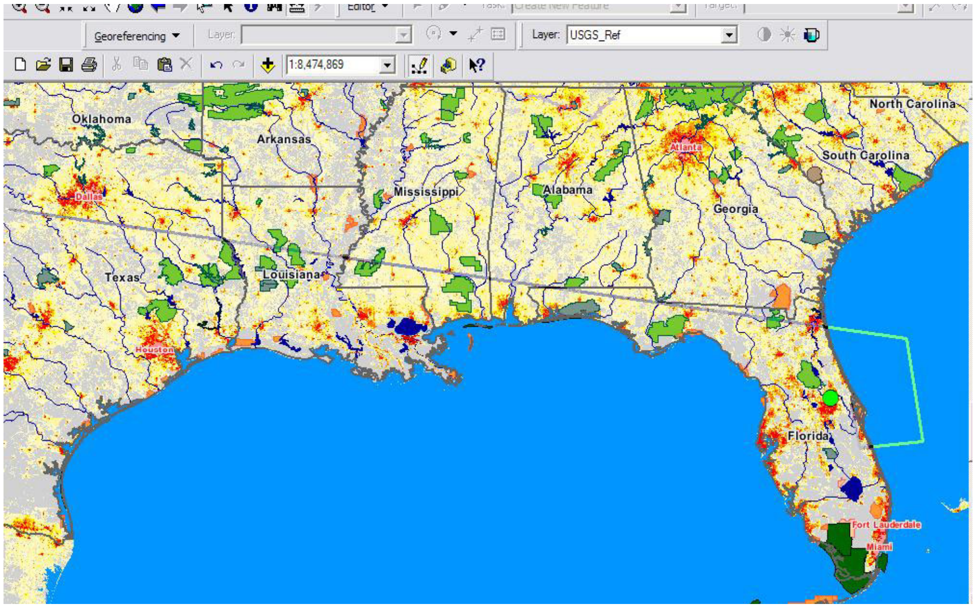

Figure 6: A LandScan Image Overlaid on a Vector Map (USGS)

-sion techniques to evaluate the combined effect of those hazards, taking into account the fact that these hazards, originating from the same source, are not independent of each other. The data fusion techniques described in this section (Distribution Envelope Determination and Dempster-Shafer Belief Functions) provide ways to fuse information that are either uncertain or dependent. Based on our initial analysis, we believe that among all the fusion methodologies, these two offer some of the greatest potential.

5.1 Distribution Envelope Determination

Distribution Envelope Determination (DEnv), also known as Interval Based Dependency Bounds Analysis, was developed by Berleant and Goodman-Strauss (Daniel & Chaim 1998) in 1998. DEnv is an uncertainty propagation, convolution-based method for determining dependency bounds on cumulative distribution functions (cdfs) for the results of binary arithmetic operations (+, -, $\times$ and $\div$) on random variables (*A* and *B*) when the inputs cdfs may themselves be uncertain (Regan Helen M, Ferson Scott, & Daniel Berleant 2004c). In our case, the random variables would be the expectation of casualties E_c resulting from the three hazards (blast, gas dispersion and debris fragmentation). The merit of this discretization method (Discretization is an alternative method to Monte Carlo simulation in problems requiring fusion of independent sources. For more information on this, we refer the interested reader to (Daniel, 1993; Ferson 1996) resides in the fact that it was developed to address cases where the dependencies between the random variables to be fused are not fully specified. Some of the key points in favor of this approach are:

- When one cannot or should not assume independence between the sources to be fused, DEnv is able to fuse those sources whether their dependency structure is completely unknown or only partially known.
- In the case where the dependency structure is completely unknown, DEnv generates bounds that are not "too conservative." The issue concerning bounds that are excessively wide, or "hyperconservative," was discussed in (Ferson & Long 1995)

Suppose we have two E_c (*A* and *B*) which are the E_c determined from the blast model and the debris model respectively. Suppose these measurements can be represented as probability density functions (pdfs) $f_A(x)$ and $f_B(x)$. The objective is to construct an upper and a lower bound on the distribution of a new variable *Z*, the combined E_c, by defining it as $Z=A*B$ where

$$* \in \{+,-,\times,\div\}.$$

Step 1: Discretize $f_A(x)$ and $f_B(x)$ using histograms. This discretization can be done by partitioning the range of values of *A* and *B* into intervals (A_i's and B_j's) and calculating the probability under the curves $f_A(x)$ and $f_B(x)$. Similar to a copula based approach, this discretization is information-losing rather than approximating, since, as illustrated in Figure 8, there is no information on how the probability mass is distributed within each bar of the histogram. The dotted lines show a few members of the family of density functions corresponding to the same discretization

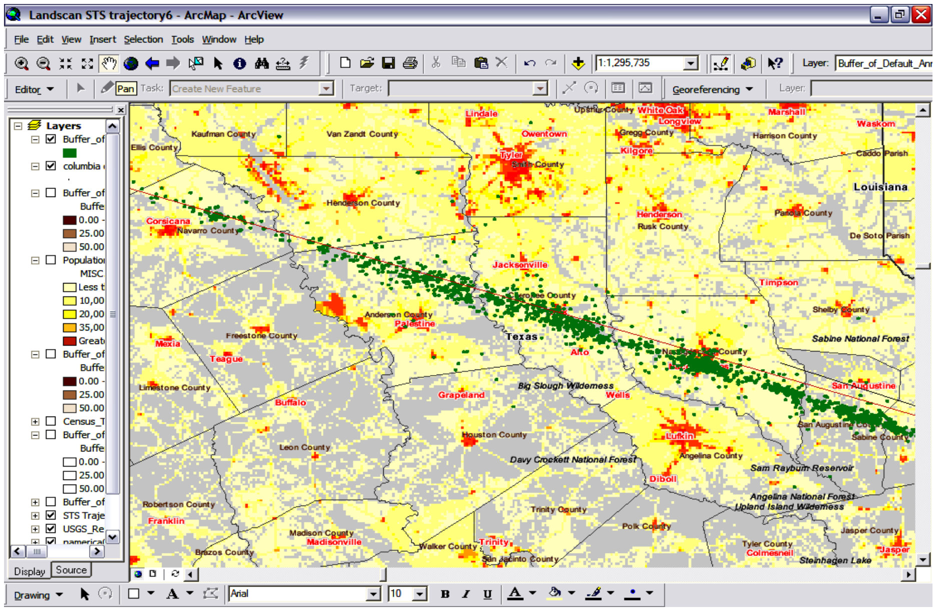

Figure 7: Debris Layer Based on 7,147 Debris Pieces Recovered from Columbia.

(Daniel 1993)

Step 2: Using histograms, we can reformulate the densities as

$$f_A(x) = \{P(x \in A_i) = p_i : i = 1,\dots, n\}$$

and

$$f_B(y) = \{P(x \in B_j) = p_j : i = 1,\dots, m\}$$

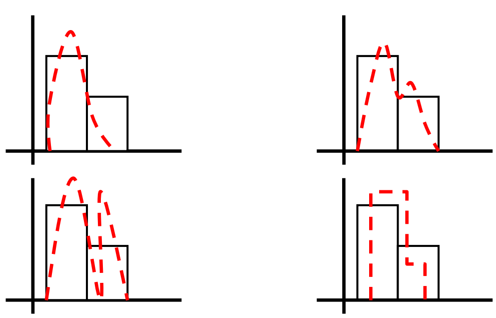

Figure 8: Discretization Leads to a Loss of Information

where the p_i's and p_j's are probability measures associated with each interval A_i and B_j, respectively. A generated range of intervals (such as the A_i's) with accompanying probabilities, as shown in Figure 9, is called a *thicket* to suggest that those intervals may overlap (Regan Helen M, Ferson Scott, and Daniel Berleant 2004). By performing this discretization for each source, the fusion process becomes the fusion of a set of intervals rather than the fusion of probability distributions. Figure 9 shows how the discretization can lead to intervals that may overlap.

Step 3: Derive the two dependency bounds by determining, for each point z on the domain of Z, the highest and lowest cumulative probabilities (the extremes) that are possible for any dependency relationship between the sources A and B. Since the extremes have staircase shapes, one only needs to select the z at which discontinuities occur.

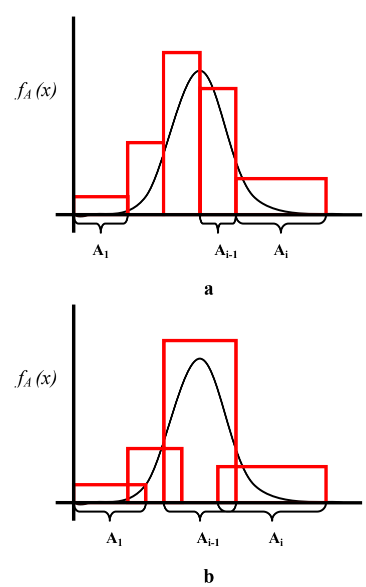

Figure 9: Pdf Discretization (Regan Helen et. al.)

The authors developed STATOOL, a software in which DEnv is implemented for two or more variables. Figure 10 is a representative output of this tool. It shows the upper and lower envelopes on the cumulative distribution of a variable Z= A*B.

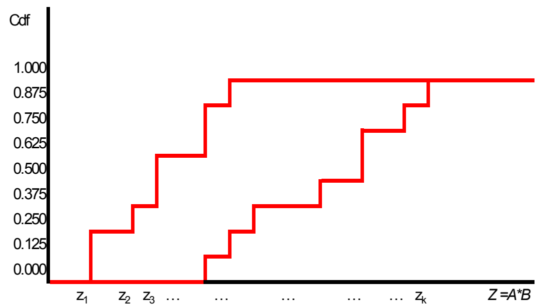

Figure 10: Envelopes on the Distribution of a Variable Z

5.2 Dempster-Shafer Rule of Combination

Within the framework of evidence theory, Dempster-Shafer (D-S) fusion methodology, also known as the theory of belief functions, is widely recognized as the most popular uncertainty propagation method. It is a generalization of the Bayesian probability calculus. As opposed to the DEnv approach to data fusion we described above, we could consider the output of each model as random variables, i.e. the blast overpressure from the blast model, the toxicant concentration level from the gas dispersion model, and the debris footprint from the debris model. Note that here, the random variables do not have the same physical meaning.

Belief functions are probabilities that are constructed from evidence. However, a fundamental difference between traditional probability – which includes Bayesian probability – and belief theory is that in the former, evidence can only be assigned to a single hypothesis (a singleton), while in the latter evidence can be assigned to a set of hypotheses. The theory of belief functions is based on two ideas:

1. The idea of obtaining degrees of belief for one question from subjective probabilities for a related question
2. The Dempster's rule for combining (or "fusing") such degrees of belief when they are based on independent sources of evidence (Glenn Shafer 1990).

Although the D-S theory was originally developed to only fuse sources under the assumption of independence between them – an assumption which is sometimes unrealistic in some applications – some authors have recently shown that this assumption can be relaxed (Regan Helen M, Ferson Scott, and Daniel Berleant 2004;Wojciech Pieczynski 2000). Regan et al, have shown that belief functions perform similarly to dependency bounds convolutions, Distribution Envelope Determinations (DEnv), and interval probabilities when they are restricted to cumulative distributions on the positive reals.

The main advantage of the D-S theory is its ability to effectively quantify the uncertainty (or ignorance) of a source about a given hypothesis. This ignorance is generally quantified with three fuzzy measures: the belief measure (*Bel*), the plausibility measure (*Pl*), and the basic probability assignment (m). A fuzzy measure μ on Θ is a mapping from subsets of Θ into the unit interval (Yager 1999, Yager 2004), $\mu : 2^{\Theta} \rightarrow [0,1]$, such that

- $\mu(\varnothing) = 0$
- $\mu(\Theta) = 1$
- $\mu(A) \geq \mu(B)$ if $B \subset A$.

The basic probability assignment (bpa), belief, and plausibility are defined within the following framework: Given a set Θ of N exhaustive and mutually exclusive hypotheses, also called the *frame of discernment*, defined as

$$\Theta = \{H_1, H_2, \ldots, H_N\}$$

for which the power set is formulated as

$$2^{\Theta} = \{\underbrace{\varnothing, H_1, \ldots, H_N}_{\text{Singletons}}, \underbrace{(H_1 \cup H_2), \ldots (H_1 \cup \ldots \cup H_N), \Theta}_{\text{Set of Hypotheses}}\}.$$

For example, we could possibly have two hypotheses (H_1: There is a casualty versus H_2: There is no casualty). We could have more hypotheses if we are interested in the type of injury, therefore generating a more detailed frame of discernment. The bpa function or m-function

$$m_i : 2^{\Theta} \rightarrow [0,1]$$

assigns a mass $m_i(A_j)$, from a source of information i (one of the three hazard models) to a singleton or set of hypotheses A_j of 2^{Θ} (In D-S theory evidence can be assigned to a single hypothesis as well as to a set of hypotheses). This probability mass represents how strongly the evidence from source i supports A_j (O.Colot, P.Vannoorenberghe, and E.Lefevre 2002).

An information source assigns mass values only to those hypotheses for which it has direct evidence. That is, if an information source cannot distinguish between two propositions A_j and A_k,, it assigns a mass value to the set including both propositions, i.e. $A_j \cup A_k$ (Valerie Kaftandjian et al. 2003). The m-function verifies the fuzzy properties mentioned above:

- $m_i(\varnothing)=0$
- $\sum_{A\subseteq 2^\Theta} m_i(A)\le 1$

Note that the m-function differs from basic probabilities as its sum does not necessarily add up to 1. The belief measure $Bel_i(A_j)$ and the plausibility measure $Pl_i(A_j)$ on hypothesis A_j of source i can be seen respectively as the lower and upper bounds on the probability $m_i(A_j)$, and are obtained as follows:

- $Bel_i(A_j)=\sum_{B\subseteq A_j} m_j(B)$
- $Pl_i(A_j)=\sum_{A_j\cap B\neq\varnothing} m_j(B)$

where any B, subset of A_j, is called a focal element provided $m_i(B) > 0$.

Considering the power set 2^Θ instead of the frame of discernment Θ only, as in the Bayesian inference case, allows for the quantification of uncertainties between sets of hypotheses.

6 DISCUSSION AND CONCLUSION

The present study seeks to enhance the capabilities of the VR by enabling it to predict the E_C from three different hazard sources rather than from only one. In one case, we showed that despite the limited capability of the software at hand, reliable results could be obtained by using a hybrid approach. In the other case, we illustrated the resolution problem associated to the addition of a new layer of ArcMap® added onto the map already used by the gas dispersion model.

The VR was designed to be modular since its conceptualization, allowing for interchangeability between software. Therefore, the goal of this study is to illustrate that despite a number of difficulties, a full integration of additional hazard models is possible in the VR and that once more sophisticated modeling tools such as CRTF (for debris) and BlastDFO (for Blast) are available, more comprehensive results (E_C due to the three hazards) can be determined.

However, simply determining the E_C resulting from these hazards by developing three layers, independently, may result in estimations that are too conservative (E_C that is way too high), prompting local authorities to deploy excessive resources which may not be available. The use of information fusion, which we are currently investigating, should allow for a more accurate (more precise) determination of the expectation of casualties resulting from the combined effects of these hazards by taking into account the interaction between those effects.

REFERENCES

CAIB Report. 2003. Determination of debris risk to the public due to the Columbia breakup during re-entry Technical Report No. 03-517-01, Columbia Accident Investigation Board, Acta Inc.

Daniel, B. 1993. Automatically verified reasoning with both Intervals and probability density functions, *Interval Computations* 2: 48-70.

Daniel, B. & Chaim, G. 1998. Bounding the results of arithmetic operations on random variables of unknown dependency using intervals. *Reliable Computing* 4 (2): 147-165.

Ferson, S. & Long, T. 1995. Conservative uncertainty propagation in environmental risk assessments. In *American Society for Testing and Materials 3 [ASTM 1218]*, ed. Hughes, J, Biddinger, G., and Mones

Glenn Shafer. 1990. Perspectives on the theory and practice of belief functions. *International Journal of Approximate Reasoning* 4: 323-362.

O.Colot, P.Vannoorenberghe, & E.Lefevre 2002. Belief function combination and conflict management. *Information fusion* 3 (2): 149.

Regan Helen M, Ferson Scott, & Daniel Berleant. 2004. Equivalence of methods for uncertainty propagation of real-valued random variables. *International Journal of Approximate Reasoning* 36 (1): 1-30p.

Sepulveda, J. A., Rabelo, L., Park, J., Martínez, O., & Gruber, F. 2004. factors affecting the expectation of casualties in the virtual range toxicity model. In *Proceedings of the 2004 Winter Simulation Conference*, ed. Ingalls R.G. et al.

Sepúlveda, J. A., Rabelo, L., Park, J., & Compton, J. 2004. A modeling and simulation environment for space ranges. In *Proceedings of the 2004 IIE Annual Conference.*

Valerie Kaftandjian., Olivier Dupuis, Daniel Babot, & Yue Min Zhu. 2003. Uncertainty modeling using Dempster–Shafer theory for improving detection of weld defects. *Pattern Recognition Letters* 24: 547-564.

Wojciech Pieczynski. 2000. Unsupervised Dempster-Shafer fusion of dependent sensors. In *4th IEEE Southwest Symposium on Image Analysis and Interpretation* ed. IEEE Computer Society, Austin, Texas, 247-251.

Yager, R. R. 1999. A class of fuzzy measures generated from a Dempster-Shafer belief structure. *International Journal of Intelligence Systems* 14 (12): 1239-1247.

Yager, R. R. 2004. Cumulative distribution functions from Dempster-Shafer belief structures. *IEEE Transactions on Systems, Man and Cybernetics* 34 (5): 2080-2087.

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