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A CHEMICAL CASUALTY MODEL

by

Paul D. Thornton

September, 1990

Thesis Advisor: Laura D. Johnson

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Currently, to plan chemical weapons' use on the battlefield, planners use the classified chemical weapon effects tables contained in FM 3-10B and look up the expected casualties based on the meteorological and target conditions. This can be a lengthy and time-consuming process especially when many weapons are available and/or many targets are under consideration. Mathematical models could significantly improve both the speed and accuracy of the current procedure and thus allow chemical weapons to be exercised more frequently. This thesis develops a model for one chemical agent and delivery system. A large simulation experiment was conducted to gather the expected number of casualties for each combination of meteorological and target conditions. The results were then fit to one model through multivariate regression to provide one equation that models the expected number of casualties from this one agent. Future work could easily expand on this effort to include other agents and weapon systems.

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A Chemical Casualty
Model

by

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of the requirements for the degree of

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ABSTRACT

Currently, to plan chemical weapons' use on the battlefield, planners use the classified chemical weapon effects tables contained in FM 3-10B and look up the expected casualties based on the meteorological and target conditions. This can be a lengthy and time-consuming process especially when many weapons are available and/or many targets are under consideration. Mathematical models could significantly improve both the speed and accuracy of the current procedure and thus allow chemical weapons to be exercised more frequently. This thesis develops a model for one chemical agent and delivery system. A large simulation experiment was conducted to gather the expected number of casualties for each combination of meteorological and target conditions. The results were then fit to one model through multivariate regression to provide one equation that models the expected number of casualties from this one agent. Future work could easily expand on this effort to include other agents and weapon systems.

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GRAFSTAT is provided to the Naval Postgraduate school by the IBM Corp. as a test of its utility on mainframe computers. Dr. Richard Welch has been instrumental in making this possible.

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I. INTRODUCTION

A. PURPOSE

The current methods of chemical fire planning are very time intensive requiring specially trained officers or noncommissioned officers (NCOs) to page through tables and select the best weapon system, agent and number of rounds to fire. This effort, even when automated, is too slow for the speed of the future battlefield. One main reason chemical warfare is not exercised as much as nuclear warfare is that the assessment of the attack takes too long and degrades the play of the exercise. The purpose of this thesis is to determine if a mathematical model can be produced that will adequately predict the number of chemical casualties expected from a particular chemical agent attack. This will allow an automated method for accurately selecting the best chemical agent and number of rounds to use against a particular target thereby making the chemical targeting process significantly more timely, efficient and responsive to the demands of the modern battlefield.

B. SCOPE

The employment of chemical weapons is dependent on a variety of variables that can be loosely categorized as either meteorological or target variables. Meteorological variables consist of air temperature, wind speed, and atmospheric stability category. Target variables are the target size and orientation, the number of rounds to be used, the breathing rate, and the Mission Oriented Protective Posture (MOPP) of the target elements. Due to the large number of values possible for these variables, a complete analysis would be prohibitive. Therefore, a mathematical model was developed for only one agent and one delivery system combination against a variety of weather and target combinations.

By using one of the current U.S. Army computer simulation models to produce experimental data points consisting of expected chemical casualties from specific chemical attacks, we develop a mathematical model that will accurately predict the casualties that occur for one agent. Similar models for other agents and delivery systems could be found given more time and effort in the same way.

C. BACKGROUND

Chemical weapons were first used in modern warfare by the Germans on 22 April 1915 at Yprees, France. They employed simple chlorine gas from cylinders against the unprotected, defending French soldiers. Throughout the remainder of World War I, chemical weapons were used extensively by both sides. The use of chemical agents during World War I was very hazardous not only to the target but also the users. Methods of using chemical agents were not well known, and thus each employment was an experiment. Many times, the wind shifted unexpectedly and the employers became the casualties. [Ref. 1]

In the years following World War I, all nations spoke out against the use of gas as inhumane and various treaties were signed prohibiting the use of toxic chemicals in war. These treaties, whether ratified or not, were respected as chemical agents were not a factor in World War II, the Korean War, or Vietnam. In fact, the Chemical Corps was cut back severely during these years, and temporarily disbanded in 1972.

Equipment that was found during the Arab-Israeli war of 1973 provided the intelligence community with overwhelming evidence that the Soviets, and Soviet backed forces, were well equipped to fight in a chemically contaminated environment. This lead to a rapid resurgence in the development of chemical defensive and later, offensive capabilities of the United States military.

During the 1980's, the use of chemical weapons has seen an increase. Reports of the use of "Yellow rain" and other similar agents in Afghanistan, and neighboring countries by Soviet forces support this claim [Refs. 2,3]. The war between Iraq and Iran was fought with heavy use of chemical agents, mostly mustard and mustard type weapons [Ref. 4].

If the United States ever has to use chemical agents in time of war, we must be able to use them in the best way possible. The current methods of chemical target analysis are too time consuming and unwieldy for the fast paced battleground of today. Chemical targeting procedures need to be automated to the maximum extent possible. This will enable the commander to make rapid decisions and thus influence the battle with all his available weapons as they are approved by the National Command Authority.

II. METHODOLOGY

A. CURRENT PROCEDURES

The current methods of chemical fire planning are time intensive and therefore inefficient. Chemical fire planning starts with the commander's guidance at either Corps or Division level. The commander's guidance usually includes the following items:

1. The time period in which chemical weapons use has been approved or for which approval is expected.
2. Tactical situation being supported by chemical weapons.
3. The desired casualties, both the type, either immediate or delayed, and the percentage or level of coverage in the target area.
4. The troop safety or other limiting requirements, such as operational considerations, civilian/host nation concerns, or no long term contamination.

The next most important information, the current weather situation, is obtained from either the U.S. Air Force Air Weather Service(AWS) or the U.S. Army Field Artillery Meteorological (Met) section. The AWS is responsible for providing forecasts for specific target areas upon request. The Field Artillery Met section periodically survey the current meteorological conditions at or near their firing sites. The Field Artillery data would not be used unless the planners had no other recourse, and the mission was time critical. The AWS information is critical to the chemical fire planning effort as the effects of chemical weapons are highly dependent on the surface air temperature, air stability, wind speed, wind direction, humidity and precipitation in the target area.

Based on the commander's guidance and the AWS meteorological data, specially trained officers or noncommissioned officers (NCOs) search the tables of FM 3-10 series manuals for applicable chemical weapons employment data to determine the optimum agent to use, the number of rounds required, the method of employment and the percentage of casualties expected from the attack. These procedures have been automated to allow a computer to access these same tables and perform the same search as the officers/NCOs. This effort, even when automated, is too slow for the speed of the future battlefield. One main reason chemical warfare is not exercised as much as nuclear warfare is that the assessment of the attack is either unrealistic or it takes too long, thereby retarding the pace of the exercise.

Another way to generate these numbers is to use a computer simulation to mathematically model the chemical cloud against the target of interest. The U. S. Army Nuclear and Chemical Agency (USANCA) has such a program called Yet Another Chemical Casualty Assessment Program (YAC). YAC is a FORTRAN based computer simulation developed at the U.S. Army's Chemical Research Development and Engineering Center at Aberdeen Proving Grounds. YAC, as originally written, contains four programs that mathematically model the cloud produced by the chemical rounds fired. Secondly, YAC models the movement and eventual dissipation as the meteorological conditions in the target area interact with the cloud. Finally, YAC estimates the percent of the target area covered with four levels of contamination: none, threshold, incapacitating and lethal.

In order to make this program easier to use and circumvent memory limitations, USANCA added three programs to YAC, two of which are preprocessors that take the user's input parameters and arrange them into a format compatible with YAC. The last is a postprocessor that transforms YAC's output into easily understandable format. For the remainder of this paper, YAC will be used to refer to the simulation program as implemented at USANCA.

This program is not the only program available but is one of the main production models for chemical casualty prediction. One thing that is common to all chemical attack simulations is that they are all computationally intensive and require a long time to run even one attack. Finally, open air testing of chemical weapons has not been done in this country in decades, therefore the only data we have is that generated by simulations such as YAC.

B. SIMULATION MODEL

YAC uses a gaussian plume model and represents the chemical cloud as a numeric matrix. This matrix is created by stochastically determining the impact point of each round fired at the target. The resulting small clouds are combined together as one numerical matrix for the remaining programs of YAC.

In order to model the movement and dissipation of the chemical cloud over time, YAC requires the meteorological conditions in the target area. These variables include air temperature, air stability, humidity, wind speed and direction, sky condition, minimum deposition level, and height of interest. YAC models the interaction between the target elements and the chemical cloud through agent and target variables, which include: agent type, the target dimensions, alignment, level of damage of interest, the

breathing rate and finally the protective posture of the target elements. All of these variables are used to produce the estimated casualty levels.

III. EXPERIMENT SET UP

A. ASSUMPTIONS

In order to show that a mathematical model could adequately predict the percent of chemical casualties from a given chemical attack, data had to be collected in an organized and limited way. Because of the lack of real field data, a stimulation model would have to be used to gather this data. YAC was offered for this purpose. This assumes that YAC is an accurate predictor of chemical casualties that will be produced from a given chemical attack. While YAC is not the only available model for this purpose, it has been developed for this purpose and has been through many U.S. Army reviews.

Secondly, it was assumed that if an equation for one agent and delivery system combination could be found, future work along similar lines could produce equations for all possible combinations of agents and weapons. Therefore, one agent from the current inventory and an appropriate delivery system were selected for this work.

Finally, the standard set of targeting assumptions were used. The target elements are assumed to be randomly and uniformly distributed throughout the target area. The range to the target from the firing site was assumed to be two-thirds of the maximum range of the weapon system. The weapon itself is assumed to operate as designed.

B. VARIABLE SELECTION

Despite the assumptions above, YAC allows for approximately twenty variables to be input that directly affect the modeling of chemical casualties. If only two values were selected for each of these twenty variables, the full experiment would entail 2^{20} runs or 1,048,576. In order to reduce this total number of experiments to a reasonable level, the variables were reviewed and the most important eight were selected. These eight variables are identical to those considered by target planners while computing expected chemical casualties using current procedures. The variables excluded are those specified by FM 3-6 as not affecting agent persistency and consequently target response.

1. Meteorological Variables

There are six meteorological variables that govern how fast the chemical cloud moves, dissipates, and how the model simulates it. Of these six, three were considered as variables and the remaining three were set to a constant value.

- The surface type of the target area was made constant at type four, which is grassland with scattered trees, brushland and scrub growth. This category is a standard starting category for use in targeting. This value is changed upon exact knowledge of the target area to be engaged. This category is also the most widely understood because of live agent field testing.
- The minimum deposition level and the height of interest were also set at constant values of 0.1 mg/m^3 and 0.5 meters respectively. The minimum deposition level determines the lowest level of chemical agent that the model will follow. The height of 0.5 meters best represents the height at which the target elements will have their noses, therefore, the height at which they will be breathing.
- The wind speed was varied between two and eight meters per second, in two meter per second intervals, as these wind speeds bound those found in FM 3-10, Chemical Employment Doctrine, and FM 3-3, NBC Contamination Avoidance. Respectively, these manuals represent our current offensive and defensive doctrine for chemical weapons employment. FM 3-6, Field Behavior of NBC Agents, specifies wind speeds comparable to this range as acceptable for the use of chemical agents. The lower bound that YAC can model is 0.5 meters per second.
- The temperature was varied between 30 and 105 degrees Fahrenheit in increments of 15 degrees. This range goes from the freezing level of many agents to the maximum temperature considered feasible for combat.
- The Pasquill stability category ranged over six of the stability categories, labeled A through F, as listed in both FM 3-6 and FM 3-3. The Pasquill stability categories are determined by the difference in air temperature at one meter and four meters. Category A, an unstable condition also referred to as lapse, means that the lower air temperature is warmer than that of the layer above it. Since hot air rises, the chemical cloud is quickly dissipated as the agent is carried up with the rising air. Category F is the most stable condition, allowing the agent to remain at ground level for a long time. The alphabetic characters A through F are entered into the YAC model as integer values from one to six respectively.

Table 1. METEOROLOGICAL VARIABLES FOR THE EXPERIMENT

Meteorological Variables		
Variable Name	Type	Value(s)
Surface Type	Constant	4
Minimum Deposition	Constant	0.1 mg/m^3
Height of Interest	Constant	0.5 meters
Wind Speed	Varies	2, 4, 6, or 8 meters/second
Temperature	Varies	30, 45, 60, 75, 90, or 105 degrees F
Stability Category	Varies	1, 2, 3, 4, 5, or 6

2. Weapon Variables

Five weapon system characteristics govern how chemical rounds are fired at the target. These variables specify the aspect of the target from the firing site, the number of rounds, the target dimensions, and the wind orientation. The values for these variables were selected as follows:

- The number of tubes per battery was set to a constant six. This variable determines how many aimpoints will be engaged by the battery.
- The number of rounds considered was 6, 12, 24, 48, 72, and 96. This assumption is based on the field artillery firing doctrine of battery fire. Since the batteries are composed of 6 guns each (assumption above), the number of rounds is the number of battery volleys times six, where battery volleys was then varied between 1 and 16.
- The range to the target was set to a constant value of 2/3 of the maximum value for the weapon system under consideration. This is the standard value used for preplanned fires, and set in accordance with the standard target planning assumptions previously mentioned.
- The wind adjusted angle, that angle between the wind direction and the gun to target angle, was set to a constant value of 270 degrees. This corresponds to the gun tube facing directly into the wind when firing at the targets.

3. Target Variables

Six possible target variables determine the size and shape of the target, the target orientation, the target location error, the number of replications of the target, and the beginning random number seed. These variables were set as follows:

- All targets considered were circular. This eliminates the need for a variable called the target facing angle, specifically that angle formed between the wind direction and a line through the long axis of the target. Additionally, circular targets present the same target picture regardless of the angle between the wind direction and gun to target line. Since the target picture is independent of the angles involved and the assumption that the target elements are assumed to be dispersed randomly and uniformly over the target area, the results will be independent of the target orientation.
- Target widths were varied as 100, 200 and 400 meters. In accordance with fire planning doctrine, larger targets could be subdivided into two or more smaller targets to fit with this simplifying assumption.
- The target location error (TLE) was allowed to vary between zero and 150 meters in increments of 30 meters. This is a measure of how accurately we can determine the location of the center of the target. Since there are errors in determining the location of the center of the target as well as in determining the actual location of the firing gun, target location errors are modeled with a standard bivariate normal distribution.
- Each target was replicated twenty times for each run in order to smooth out any stochastic variations caused by the random number generator. This also allows for

independent estimates of the variance of each data point. For a more detailed discussion, see Appendix A.

4. Posture Variables.

The three posture variables govern the protection available to the target elements, their breathing rate and the assessment time. These variables were set as follows.

- The protective posture of the target elements was set as a constant, MOPP0. This means that the target elements have no protective equipment at all. This assumption was made as the chemical agent used is a nonpersistent agent that is only an inhalation hazard.
- Breathing rates were varied between 25 liters/minute and 65 liters/minute which equates to resting and heavy work breathing rates, respectively.
- The assessment times were 15 seconds through 120 seconds. This variable relates to the persistence of the agent. Also, if the defending troops had protective masks available, it could equate to the assumed training level of the troops in the target.

5. Other Database Variables

- Agent type was set to a single type of artillery delivered nonpersistent agent as mentioned above. This will demonstrate that one equation or a small set of equations can be developed to predict the expected number of chemical casualties from a given chemical attack. Given more time, similar equations can be developed for all of the other agent types available in the inventory, as well as other delivery methods.
- The delivery system used was an U.S. Army artillery system. Appropriate equations could also be developed for threat weapon systems and agents to determine which pose the greatest threat to friendly forces. This would be instrumental in assigning priorities of fire between chemically capable enemy formations. The appropriate weapon system errors and the actual performance characteristics of the shell modeled remained constant throughout all of the experiments. The actual numbers used were obtained from USANCA.
- YAC estimates the percentage of the target that is covered with no effects, threshold, incapacitating, or lethal levels of contamination. Those portions of the target covered with lethal and incapacitating effects were consolidated to produce the expected number of casualties. This consolidation of the two effects is a common method used to insure monotonicity of the effects over time.

Table 2. TARGET SPECIFIC VARIABLES FOR THE EXPERIMENT

Target Variables			
YAC Category	Variable Name	Type	Values
Weapon	Number of Tubes per Battery	Constant	6 tubes per battery
	Adjusted Wind Angle	Constant	270 degrees
	Range to the Target	Constant	2/3 maximum range
	Number of Rounds	Varies	6, 12, 24, 48, 72, or 96 rounds
Target	Shape	Constant	Circular
	Number of Runs	Constant	20 iterations
	Radius	Varies	100, 200, or 400 meters
	Target Location Error	Varies	0, 30, 60, 90, 120, or 150 meters
Posture	Protective Posture	Constant	0
	Breathing Rate	Varies	25, 45, or 65 liters/minute
	Assessment Time	Varies	15, 30, 45, 60, or 120 seconds

C. EXPERIMENT

The above set up resulted in 144 unique experiments to cover all combinations of the six temperatures, the six stability categories and four wind speeds. Within each of these experiments, all 1620 combinations of target, weapon and posture variables were run. The casualties produced for each of the experiments is an average value for the twenty replicated targets. The final result of this experiment was a table of 233,280 multivariate data points. Each of these points is described by its eight variable values and the resulting percentage of chemical casualties. The experiments can also be divided into 46,656 unique combinations of the seven variables that are evaluated across the five different assessment times. In other words, the casualties produced in 30 seconds following an attack are dependent on the number produced in 15 seconds.

IV THE MODEL

A. DATA GENERATION

The generation of the 233,280 data points represents an enormous amount of computer time and effort. The processing was done on the Naval Postgraduate School mainframe computer during evening hours. Each unique experiment took essentially six hours of clock time to complete. The key driver to the six hours was the input/output time required by YAC. YAC is written to be an interactive program, allowing the user to specify the values of all the variables as he goes. Use of data files speeds up this process and fully automates it until it reaches the inherent speed of the computer input/output interface. As measured by the Naval Postgraduate School, this data generation effort consumed over $100,000 of computer resource money. For a full discussion of this effort, see Appendix B.

B. VERIFICATION

The data generated were verified against identical runs conducted at the USANCA to insure that transporting and running this program on the Naval Postgraduate School's system did not corrupt the FORTRAN code itself. The verification effort consisted of comparing all eleven output files from four different experiments. This insured that not only were the final numbers correct but intermediate values were also correct. Since YAC is a combination of seven unique modules that communicate through the use of input/output files created by each module, this step was very important. The results of this verification were predictable. The FORTRAN code used at the Naval Postgraduate School produced identical results to runs done at USANCA for identical input variables.

C. SENSIBILITY CHECKS

In checking the raw output of the YAC model, certain sensibility checks were possible to insure the model was acting the way live chemical agents would in a field environment. First, as assessment time increases, the number of chemical casualties should increase and asymptotically approach a limit. This limit will vary depending on the values for the remaining variables. When looking at the radius of the target and the target location error, the number of casualties produced should decrease, given that all other variables are constant, as either or both of these variables increase. The stability

category should show an increase in casualties produced as the atmosphere gets more stable, i.e., increases in value. As the breathing rate increases, the number of casualties should also. Finally, as the number of rounds increases, the amount of agent deposited in the target area increases which should be reflected in an increase in the number of casualties reported.[Ref. 5] The data generated reflected these general trends within each experiment and between experiments. These two steps were taken to support the assumption that this computer model is a reasonable simulation of true chemical agent behavior.

D. MEASURE OF EFFECTIVENESS

Once the data set had been generated and checked, the search for the best equation to explain this data set began. In order to compare models that had differing numbers of explanatory variables, the sum of squared errors was used as the measure of effectiveness. Using this value, all models were on equal footing. Additionally, the mean square error is an estimate of the model variation. Since the goal is to be able to predict the expected percentage of chemical casualties, the mean square error will be important in determining the prediction interval.

V. MODEL INVESTIGATION

A. PROCEDURES

The size of the generated data set prohibited interactive investigation due to the virtual machine memory limitations. Model investigation was performed interactively, using GRAFSTAT, on a randomly selected subset of the data. Models that performed well were further evaluated by SAS with the full data set. The subjective performance criteria used was an adjusted R^2 value in excess of 0.7 in concert with low variance inflation factors for the majority of the variables.

Many different models were investigated. The general order of investigation was simple linear models, followed by models involving variables of higher orders, and finally equations including nonlinear functions of selected variables. Transformations of the dependent variable, casualties, were also investigated. A time series model would require iterative calculations to approximate the chemical casualties expected from an attack. Since a quick and easy to use model was the goal of this work, time series models were excluded from consideration. The total number of models investigated was approximately one hundred.

B. RESULTS

The best model found is a the following equation, which has linear coefficients and an intercept term. For any chemical attack under consideration, let the parameters X_1 through X_8 be defined as:

- X_1 is the wind speed at the target area in meters per second.
- X_2 is the temperature in degrees Fahrenheit.
- X_3 is the numeric value of the Pasquill Stability category.
- X_4 is the square of the radius of the target in meters.
- X_5 is the target location error in meters.
- X_6 is $1 - e^{-0.0081276 \times rounds}$ a nonlinear function of the number of rounds fired at the target.
- X_7 is the breathing rate of the target elements in liters per second.
- X_8 is the assessment time in seconds.
- $\hat{Y}$ is the predicted percentage of expected chemical casualties times 100.

The expected percentage of casualties as a function of the explanatory variables is computed as:

$$\begin{aligned}\hat{Y}(x) = {} & 18.7043423 + 0.66273177\,X_1 + 0.01715192\,X_2 \\ & - 1.62086786\,X_3 - 0.000117055\,X_4 - 0.106486\,X_5 \\ & + 50.04623864\,X_6 + 0.1189918\,X_7 + 0.22596822\,X_8\end{aligned} \tag{1}$$

This model had a small error sum of squares, 18,441,071. The estimated standard deviation of this model, denoted $\hat{s}$, is the square root of the mean square error. The mean square error is the sum of squares divided by the degrees of freedom of the model after subtracting one for each of the parameters that have been estimated, 233,280 - 9 = 233,271. This gives a mean square error of 79.0544. The $(X'X)^{-1}$ matrix for this model is required for the calculation of the prediction interval at desired combination of parameters. The full $(X'X)^{-1}$ matrix is included in Appendix D, along with the complete SAS output, to aid in calculation of these intervals.

The x_0 is the vector of nine values, specifically a one followed by the remaining eight values, one for each 'X' variable, that describe the target situation for which a prediction interval is desired. This vector starts with a one because the model uses a constant term. Finally, the t statistic is used to determine the prediction interval based on the confidence level, α desired. Since the degrees of freedom is so large, 233,271, the $t_{\frac{\alpha}{2}}$ can be replaced by the Z values found in the normal distribution tables, specifically $Z_{\frac{\alpha}{2}}$ and $Z_{1-\frac{\alpha}{2}}$ for the lower and upper prediction limits respectively.

$$\hat{Y}(x_0) \pm t_{\alpha/2,N-p}\,\hat{s}\,\sqrt{1 + x_0(X'X)^{-1}x_0} \tag{2}$$

- Example. The expected percentage of chemical casualties is desired for the following situation: two battery fires of chemical agent (12 rounds) will be used on a 300 meter circular target with a target location error of 45 meters. Meteorological conditions at the target include the wind speed of six meters per second and a stability category of C (numeric value is 3). Finally, assume that the target elements have been working hard and consequently have a breathing rate of 45 liters per second. The expected percentage of casualties is desired for 30 seconds with a 95% prediction interval.

The situation above results in:

1. $x_0 = [1\ 6\ 30\ 3\ 300^2\ 45\ 1 - e^{-0.000127 \times 12}\ 45\ 30\ ]$ which simplifies to the following nine element vector $[1\ 6\ 30\ 3\ 90000\ 45\ 0.09293\ 45\ 30]$
2. $\hat{Y}(x_0) = 19.79$ as the predicted percentage of chemical casualties.

3. $\hat{s}\sqrt{1 + x_0(X'X)^{-1}x'_0} = 8.89$ as the standard deviation of prediction from equation (2).

4. $-t_{(\alpha/2)} = Z_{0.025} = -1.96$ and $t_{(\alpha/2)} = Z_{0.975} = 1.96$ are the multiplicative factors that correspond to a 95% prediction interval.

5. Therefore the 95% Prediction Interval is: $\hat{Y}(x_0) \pm 17.42 = (2.37, 37.21)$ the 90% prediction interval would be (5.17, 34.41) which is easily obtained by substituting 1.645 in for the multiplicative factors in equation (2) rather than the 1.96 values.

Additionally, this model was not adversely affected by outliers in the data as robust regression resulted in coefficients very similar to those obtained in linear regression. Ridge regression was run on this model to determine if collinearity was adversely affecting the coefficient estimation. The resulting coefficients were again very similar to those obtained by linear regression techniques. Lack of collinearity is also exhibited by the fairly small variance inflation factors. All eight of the parameters have variance inflation factors between the ideal value of one and 1.000095.

C. CONCLUSION

This is the best model encountered for the prediction of chemical casualties for this one chemical agent and delivery system combination. This model performs well at the lower values of $\hat{Y}$, the expected number of casualties. At values larger than 50 percent, the error tends to increase. This will not cause any problems as the prediction interval will still contain the actual value but the model will tend to under predict the casualties. This is similar to taking the worst case of the expected number of casualties, a standard targeting practice. Near the mean value of each of the explanatory variables, $\overline{X}$, is where the prediction interval will be the smallest. This prediction interval increases with an increase in the distance from the mean of the explanatory variables. Those values near the maximum or minimum values of any explanatory variable will lead to the largest prediction intervals. This equation is only valid within the range specified by the values of the variables used. Extrapolation beyond any of the ranges used could cause unreliable results.

VI. FUTURE DIRECTIONS

A. YAC MODIFICATIONS

Future work in this area should first concentrate on optimizing the FORTRAN code of YAC. As currently implemented, YAC is dependent on external storage mediums to hold the large arrays and files created during each run. These files are accessed by subsequent programs within YAC. This method of passing files is very slow and cumbersome. One large driver program should be written to control the sequence of actions within YAC and maintain the data arrays required. Modified in this manner, YAC would only require input once and output once. The real time used for each run would drastically be reduced. This would enable the experiments required for determining other equations to be run much faster and save at least 40 to 50 percent of the time used for this thesis. The one drawback to this approach is the increased requirement of YAC for random access memory. YAC would now require approximately six megabytes of random access memory to hold the files that previously were stored on external devices until required. Careful attention to the storage of the important values will entail modification of much of the FORTRAN code. The investment of time and effort required to modify YAC, as mentioned above, would be repaid in the time saved in generation of future chemical casualty equations.

B. FUTURE EQUATIONS

Research into equations that model other agents or delivery systems should continue. The appropriate equations should be developed for all U.S. weapons as well as those weapons that may be used against our forces. Chemical weapons are commonly referred to as the "poor man's nuke" because of the relative ease in obtaining these weapons of mass destruction. Recent use of these weapons by both Iraq and Iran demonstrates the willingness of many nations to use these weapons. The United States must be ready to retaliate with chemical weapons, in accordance with stated doctrine, should these weapons be used against our forces or those of our allies. Equations similar to the one developed will enable U.S. forces to accurately wargame the threat's best options for chemical use and concurrently determine the best response to that threat. All this can be done quickly using currently available targeting computers or hand calculators without overloading the capabilities of either.

APPENDIX A. JUSTIFICATION FOR 20 ITERATIONS

YAC has one routine within the IMPACT module that is stochastic. This program determines the actual impact point of each round that is fired at a target. It is stochastic to allow for the firing errors that occur, in real life, to a round in flight. YAC models these errors using an elliptical bivariate normal distribution where the longer axis is parallel to the direction of fire line.

To obtain a reliable figure for the number of casualties produced, and thus reduce the associated variance, a reasonable number of iterations to average over and report was needed. As input/output time was the driving consideration for how long each experiment took, reducing the number of iterations to a minimum was very important. A random sample of the experiments was needed to run at a high level of iterations to determine the sensitivity of the expected number of casualties to the number of iterations run. The roll function in A Programming Language (APL) was used to randomly select ten unique combinations of meteorological conditions, called experiments. The results of the random draw is tabulated below in Table 3. The experiment number, column 1, is used for reference in the graphs that follow. The remaining three columns show the randomly selected agent, target, weapon and posture data file that was used for that unique experimental instance. These values relate directly to those values found in Tables 1 and 2. These ten experiments were run through 30 iterations, the maximum number of iterations allowed by YAC.

Table 3. INVESTIGATIVE CASES

Experiment Number for Graphs	Agent Number	Target Number	Weapon Number	Posture Number
1	7	4	4	1
2	98	6	18	3
3	109	1	13	1
4	32	3	3	3
5	67	1	1	1
6	77	5	11	2
7	121	2	16	3
8	19	1	1	1
9	56	5	11	2
10	75	2	8	2

A small FORTRAN program was written to then calculate the mean number of casualties and the associated variance after each iteration for each of the ten experiments. The resulting curves were then plotted using GRAFSTAT. The first five plots, indexed by assessment time, show how the mean number of casualties produced approaches its value by iteration. The second five plots show how the variance approaches its values by iteration.

In reviewing all of the plots below, the plots associated with the higher assessment times seemed to take longer to settle down and had higher variances than the lower times. Therefore, 120 second assessment time graphs were considered as the limiting graph. These showed that the casualty level had reached its level by approximately 16 to 18 iterations and concurrently the variance had reached its limit also. This was rounded this value up to 20 to use in the final experiments.

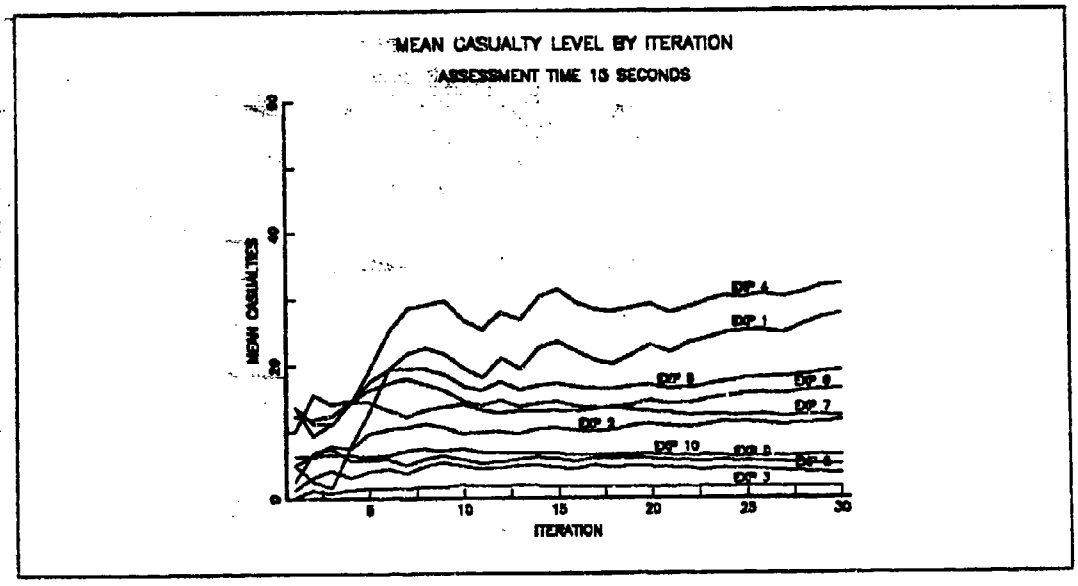

Figure 1. Mean Casualty Level, Assessment Time 15 seconds.

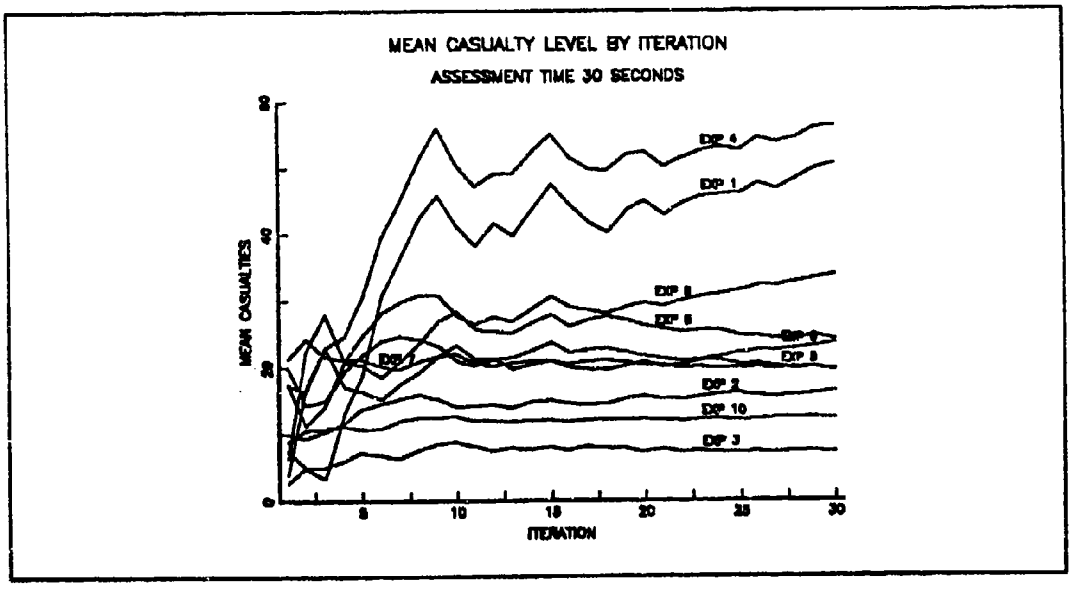

Figure 2. Mean Casualty Level, Assessment Time 30 seconds.

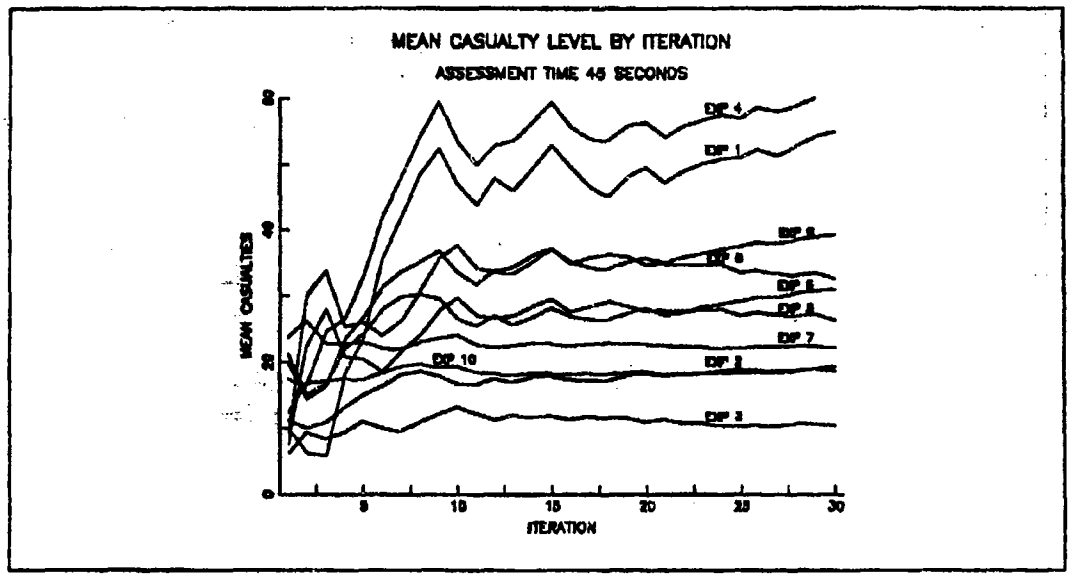

Figure 3. Mean Casualty Level, Assessment Time 45 seconds.

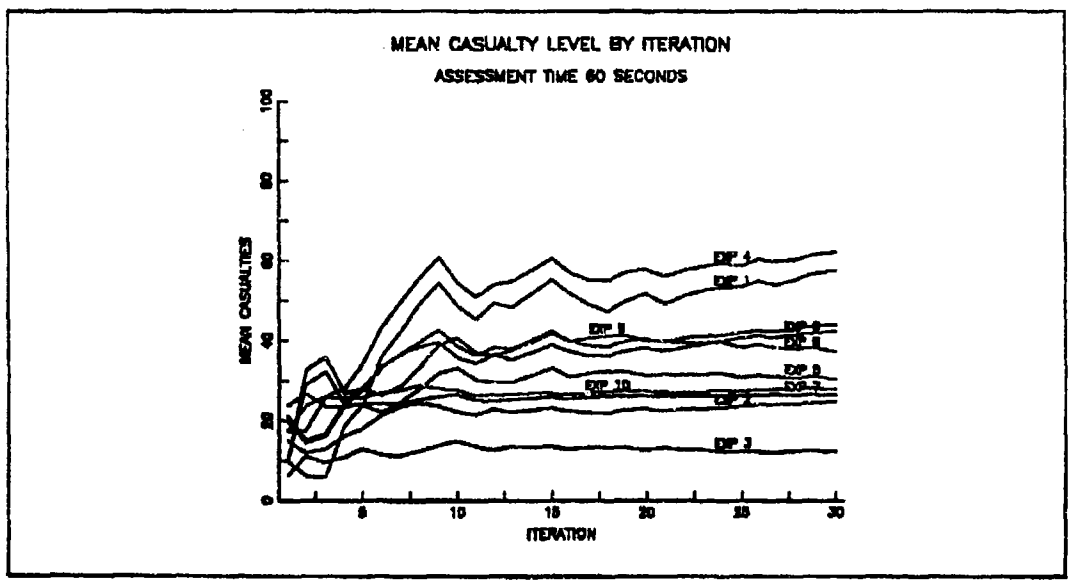

Figure 4. Mean Casualty Level, Assessment Time 60 seconds.

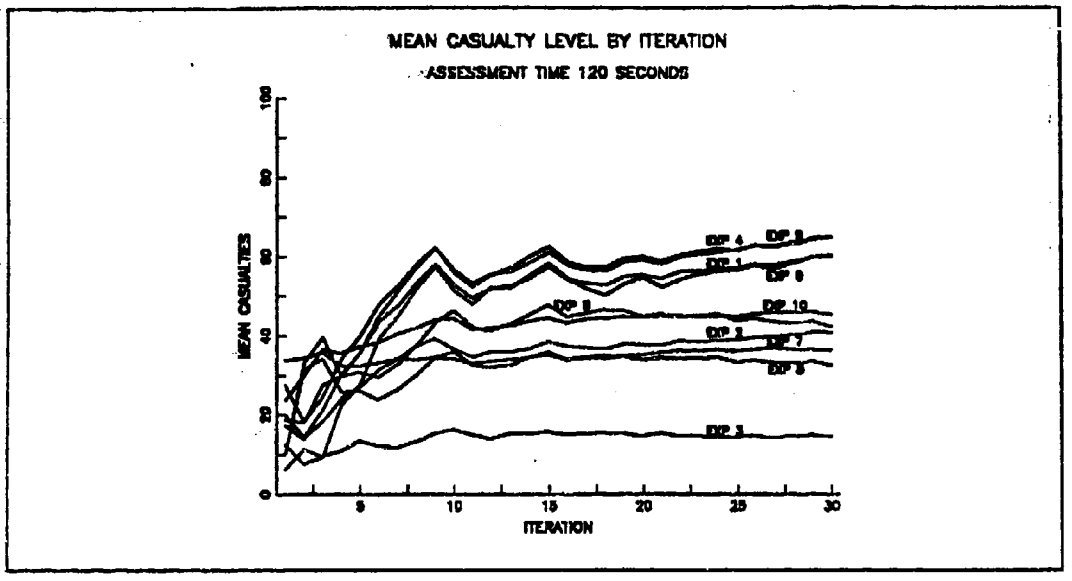

Figure 5. Mean Casualty Level, Assessment Time 120 seconds.

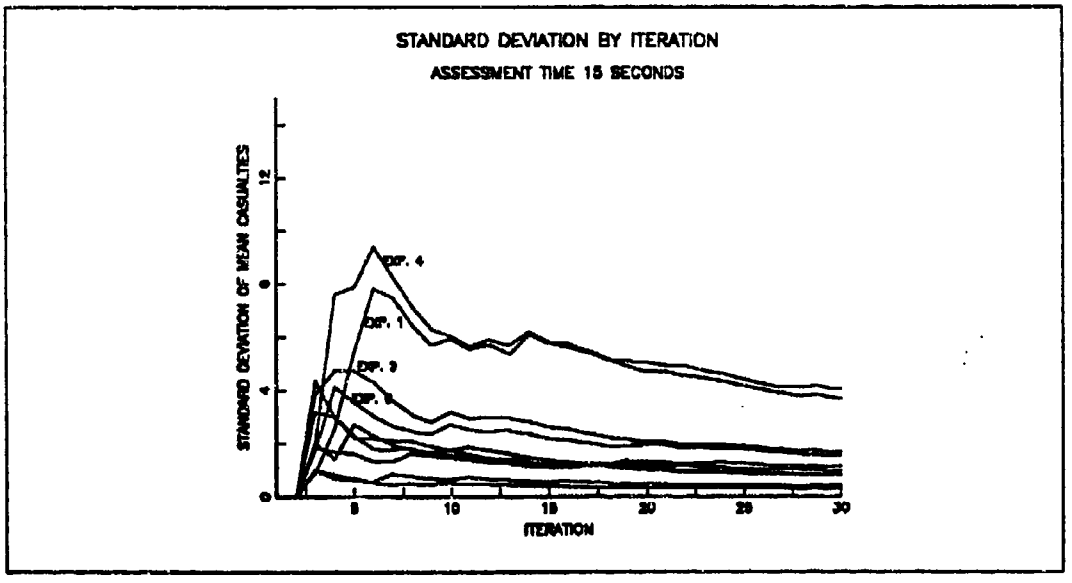

Figure 6. Standard Deviation of Mean Casualties , Assessment Time 15 seconds.

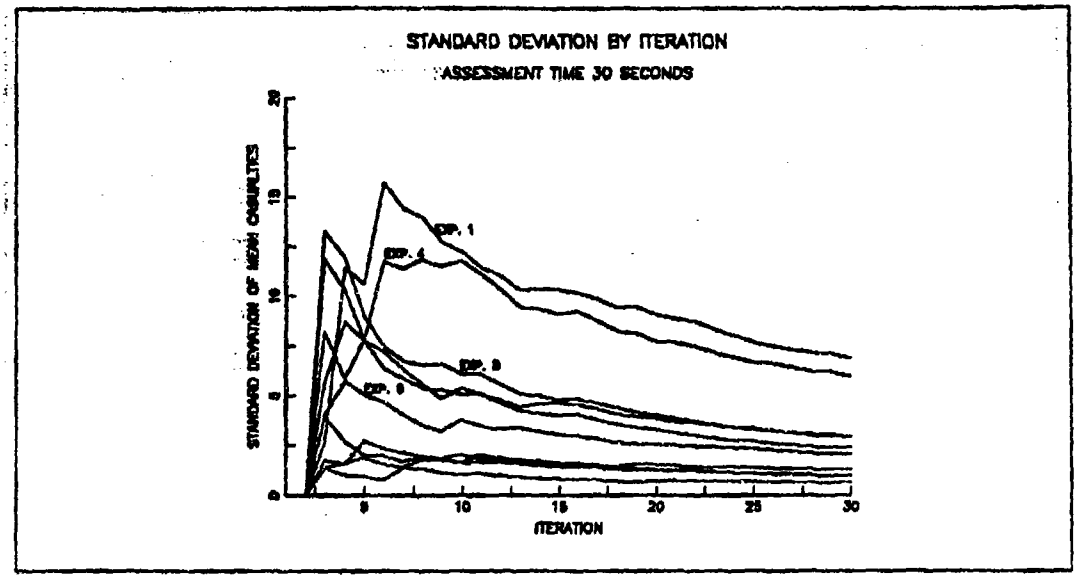

Figure 7. Standard Deviation of Mean Casualties , Assessment Time 30 seconds.

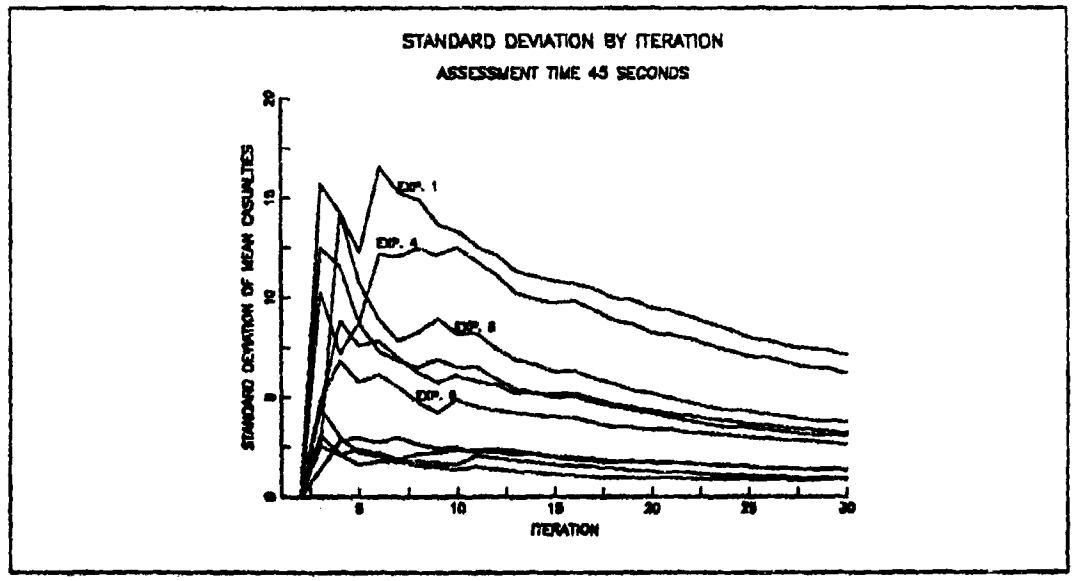

Figure 8. Standard Deviation of Mean Casualties , Assessment Time 45 seconds.

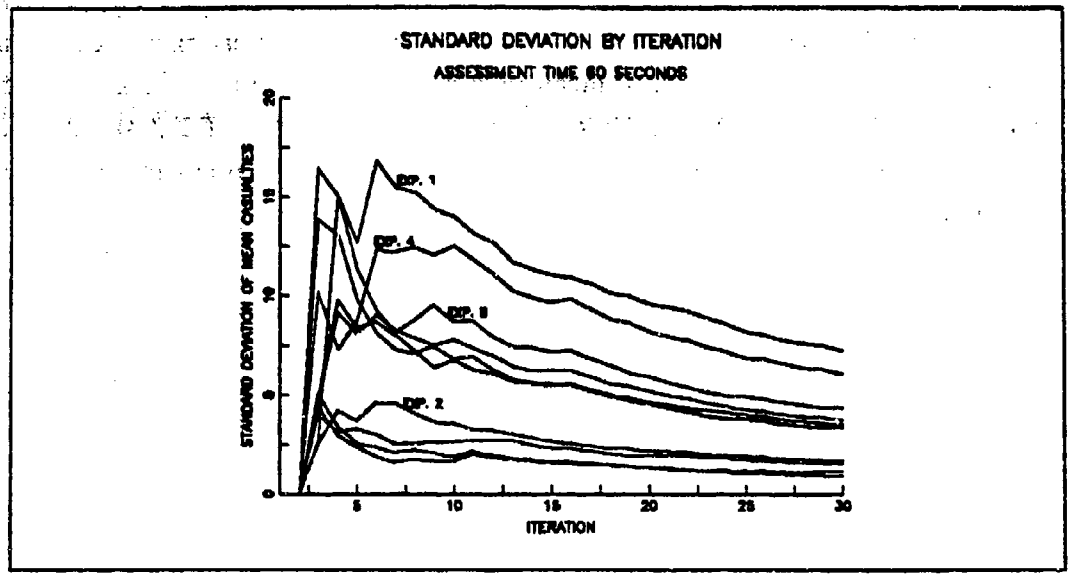

Figure 9. Standard Deviation of Mean Casualties, Assessment Time 60 seconds.

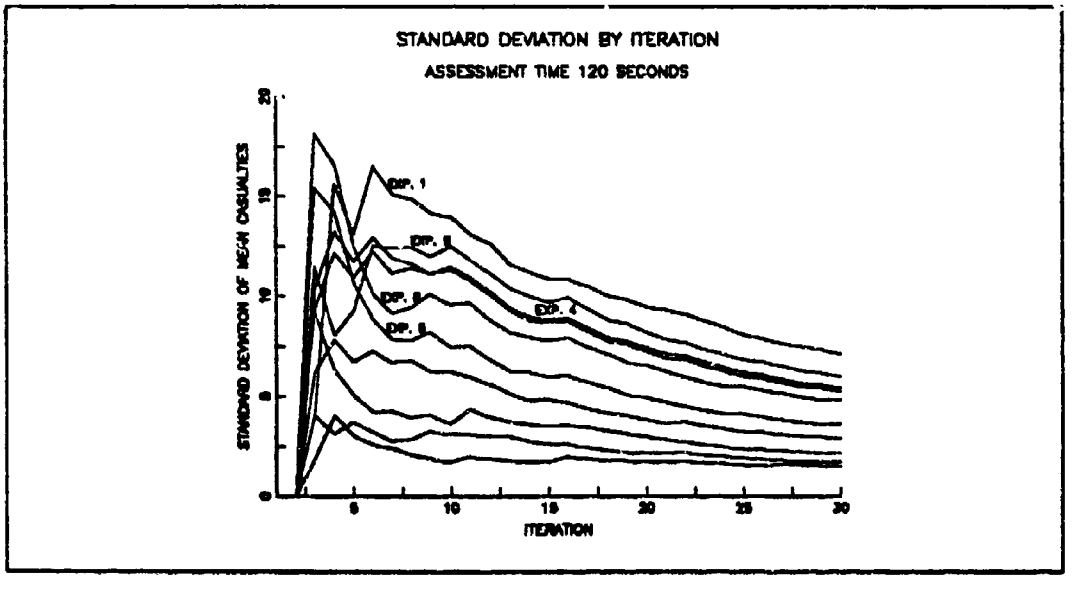

Figure 10. Standard Deviation of Mean Casualties, Assessment Time 120 seconds.

Experiment 1 was the most variant of those selected. Its standard deviation was still only slightly higher after twenty iterations than it was after thirty. This small difference,

specifically 0.293, is not significant enough to warrant the extra computer time involved in running YAC the ten extra iterations for every instance of every experiment. This effort saved running the YAC program an additional ten iterations for each of the 46,654 unique experiments, which translates into an estimated savings of 20,000 dollars of computing funds for this paper. Future work in this area will also realize savings proportional to the data collection effort.

APPENDIX B. PROBLEMS ENCOUNTERED

1. Background

The Naval Postgraduate computer system consists of three main processors for interactive use and one processor for batch processing, each running at about ten megahertz. Each user is given a virtual machine (VM) random access memory (RAM) of between 1.5 and four megabytes. YAC required a VM of 2.5 in order to run. The Data Facility Hierarchical Storage Manager (DFHSM) is implemented with 3380 disks. It provides almost limitless storage to any user. The means to move the data back and forth between the VM system and Multiple Virtual Storage (MVS), the background system, is through Job Control Language(JCL).

2. Transfer of the Code

The transfer of the YAC FORTRAN code from the USANCA was not a significant problem. The code is generally written in FORTRAN (Level 77) code without extensions. In order for the code to compile, one "SAVE" statement in one routine had to be moved within a routine. The real problem came in trying to run the code on the Naval Postgraduate School mainframe. YAC uses the FORTRAN "INQUIRE" statement to check if a file currently exists, if it does, the code then appends to the file the new information. When the file does not exist, it is created from scratch. YAC does this check [illegible] times throughout its seven main programs. As implemented here, FORTRAN VS1 (version 1.4.1) does not allow for this use of "INQUIRE", all files must first be opened. YAC had to be recompiled using the FORTRAN VS2 (version 2.3) compiler since it does allow a user to "INQUIRE" about the status of a file prior to opening it.

The second problem was in getting YAC to read the data files properly. As implemented, YAC reads data files in each of its seven main programs, many of which were created in the previous main program. This is done to get around the small virtual machine limits of the computer system it normally runs on. The computer system at the U.S. Army Nuclear and Chemical Agency is a UNIX based machine that has a workspace upper limit of two megabytes. YAC uses many direct access files to pass information from one program to another. This is very inefficient for repetitive experiments because of the input/output time involved. More importantly, for each file that was to be a direct access file, an upper bound had to be specified. This was done by trial and

error, since the USANCA computer's operating system handles this automatically; they could not provide any specifics on how large to make these files. Once this was completed, YAC was running on the Naval Postgraduate School computer.

The first few runs produced a negative value for the mean number of casualties produced for the first combination of variables of the experiment. This was obviously wrong. The error was found in one small accumulation routine. Three variables were not initialized to zero prior to the start of this routine, so the accumulation of the casualties for the very first instance of the experiment were always overshadowing by the random bit pattern that was in that memory location prior to starting the program. Addition of three lines of code that initialized these accumulation variables fixed the problem. The code then produced numbers that matched those obtained at USNCA. This was the most important step for verification of my efforts in transferring the YAC program here to the Naval Postgraduate School.

3. Time

After getting the program to run on the computer here, a benchmark test showed that it was taking approximately seven to eight hours, or one night to run each experiment through its 324 instances despite being compiled under optimize level 3, OPT(3). This compiler option has been known to increase the CPU execution time of FORTRAN programs up to 50%. The actual increase for YAC was approximately 5% because the execution time is limited by input and output time. Each instance represents a unique combination of five of the important variables being considered. Since each experiment is a unique combination of three variables, the full report would need 144 nights of computer runs without any errors. This would take too long to complete in the allotted time, so time became a problem.

In an attempt to accomplish the full experiment, the YAC code was transferred to the batch system where it could possibly run 24 hours a day. This entailed transferring all of the FORTRAN code over to the MVS system and recompiling it. No significant problems were encountered in this portion of the operation.

The next step was to run the program for one complete experiment on a dedicated processor to see if this would be fast enough to guarantee completion in the allotted time. JCL does not have provisions for a looping or iterative program structure other than by using a catalog procedure. A catalog procedure is a collection of JCL statements that may be executed in a job stream by an execute statement. In the VM side, a REXX program was written that set up the file definitions for each instance of the experiment and looped through all 324 instances in order. The batch system does

not have REXX, so JCL had to handle this portion of the work. The JCL program to run just one instance was approximately 170 lines long and contained five execute statements. After setting up this code as a cataloged procedure, another JCL program attempted to call it 324 times. JCL only allows for up to 50 execute statements in a program so this approach failed. Each experiment would have to be subdivided into seven pieces, and then run in order. Each piece consisted of sequential execute statements of the catalog procedure passing it the appropriate file definition parameters. After all that work, the batch system ran considerably slower than the VM system, even with a dedicated processor. It was taking the dedicated processor between one and 1.5 minutes to run each instance of the experiment. The majority of this time was again caused by the input and output time of the YAC modules. Each experiment would need approximately nine hours of computing time. Worse, the dedicated processor would be tied up for almost seventy consecutive days in order to complete all of the experiments. This was too high to be feasible.

To overcome this time problem, the YAC program itself had to be modified, specifically the input/output time had to be reduced. The first two main programs are only called once per experiment so they were not changed. The remaining five programs were looking at line by line, and any code that did not actually directly relate to the calculation of the casualties produced was pared out. By paying strict attention to the input/output handlers, the time for each instance was significantly reduced. This faster and trimmer version of YAC would run in slightly less than six hours of real time. Six hours meant that two experiments could be run per night, from 1800 to 0800 the next morning and not exceed the resource limits of the mainframe computer. By running YAC under two user accounts, up to four experiments could be accomplished per night, and many more over the weekends. Now the collection of data would only take about one month of running YAC every night and all weekend. The actual collection effort took a little longer than that optimistic time line because of scheduled computer maintenance and some runs being aborted when the file definitions turned out to be too small. As mentioned above, trial and error was used to determine the upper limit of the direct access files. The file produced by the CLOUD program of YAC proved to be the most difficult. It contains all of the parameters that define the cloud produced by the chemical weapons under the conditions given. It originally started with a size of 20,000 records, each 120 characters long, but ended up having 38,000 records. Most of the weapon and weather combinations ran under a size of 25,000 but four required the much larger size.

APPENDIX C. RANDOM NUMBER SEEDS

YAC has only one stochastic process in its algorithm, specifically the determination of the impact point of each round fired. In order to do this, YAC first generates a random point to be the true target center. This point is generated using a pseudorandom number generator to select coordinates from a circular normal distribution directly related to the target location error. This portion of the algorithm is in the PREPROCESSING module. Later, the IMPACT module uses these coordinates to determine how far away from the true target center each round impacts. With the use of a pseudorandom number generator, there exists the possibility that problems in the generator can cause unreliable results in the final output. To allay this fear, the investigation of the random number generator within YAC followed two courses. First, the random number generator code was removed from YAC and tested for faithful production of uniform random deviates. Secondly, YAC itself was run with an additional ten starting seeds and the output compared with that of the constant seed selected for the experimental runs.

In investigating the code within YAC for the production of random numbers, three tests where run. First, samples of 10,000 random numbers where generated with a variety of seeds and the percentiles compared to that of a true uniform distribution. In every instance, the resulting sample was close enough to a true uniform distribution that the hypothesis could not be rejected. Second, the output was graphed in various dimensions to see if dependencies existed between deviates and those that followed either immediately or up to five deviates later. Again, no patterns or suspected dependencies were discovered. This step also involved bit stripping to see if dependencies could be discovered. Finally, initial seeds where selected and the random number generator was run until that seed was encountered again. If the random number generator has no problems, every seed should run for the full cycle of the generator until it occurs again. Each of the selected seeds also passed this test. [Ref. 6] Based on this portion of the investigation there was no reason to suspect that the final YAC output would be effected by the initial random number seed selected.

Lastly, ten additional samples of the most variable experiments from Appendix A were generated with unique initial random number seeds. Using the values of the variables that corresponded to experiment 1 and ten different initial starting seeds, samples

were generated by YAC to compare with the values generated using 1234 as the initial seed. These eleven samples were used to test the hypothesis that the value of the initial random number seed used in the main experiment, did not influence the outcome. The initial seeds used in this part of the test were 1234(the base case), 1955, 4736, 13371, 251, 9965, 2487, 5037, 18123, 514, and 4916. The following five graphs show the results of this effort.

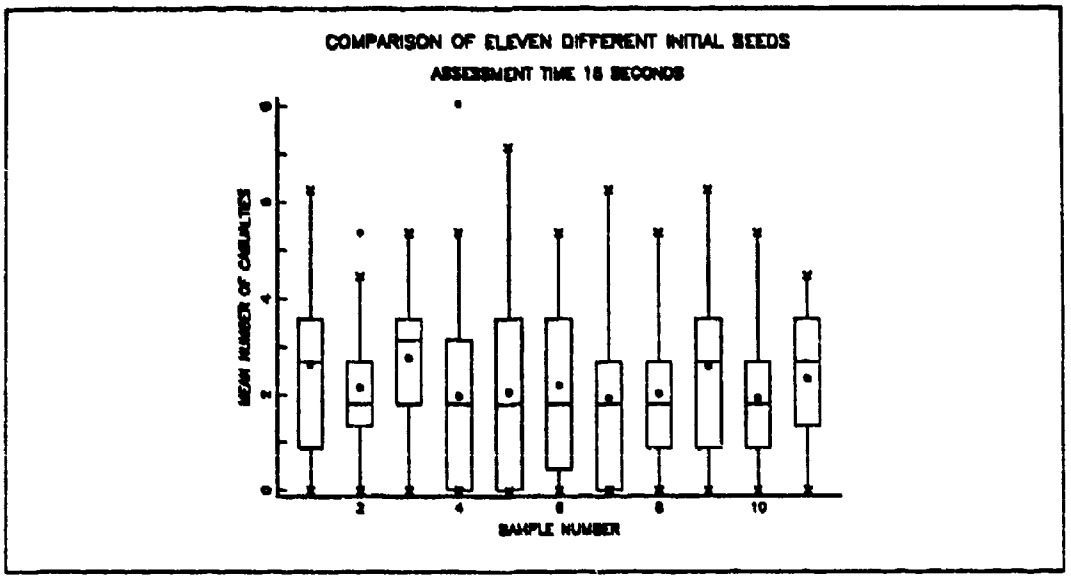

Figure 11. Comparison of Samples, Assessment Time 15 seconds.

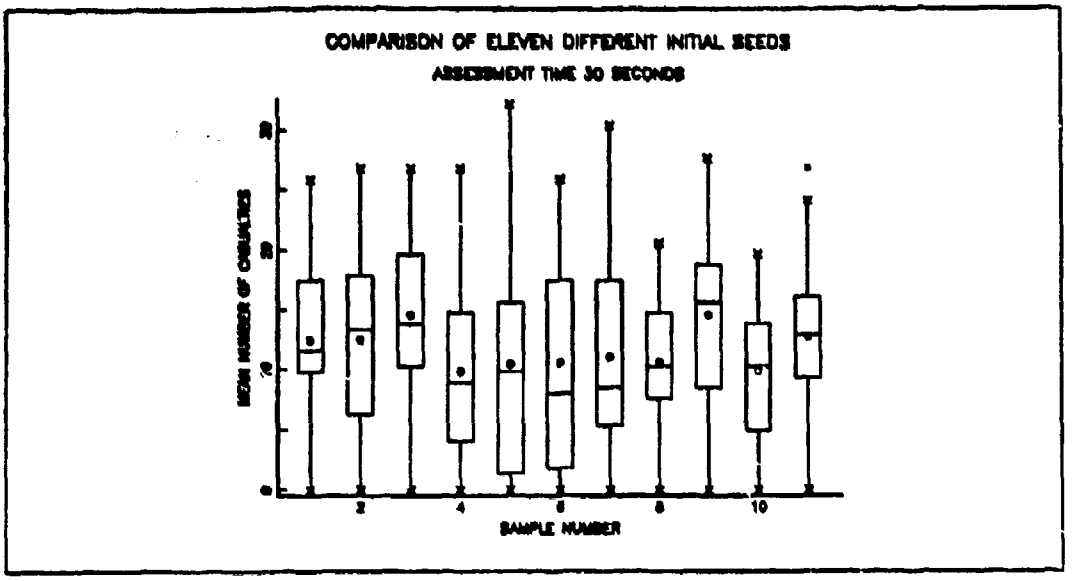

Figure 12. Comparison of Samples, Assessment Time 30 seconds.

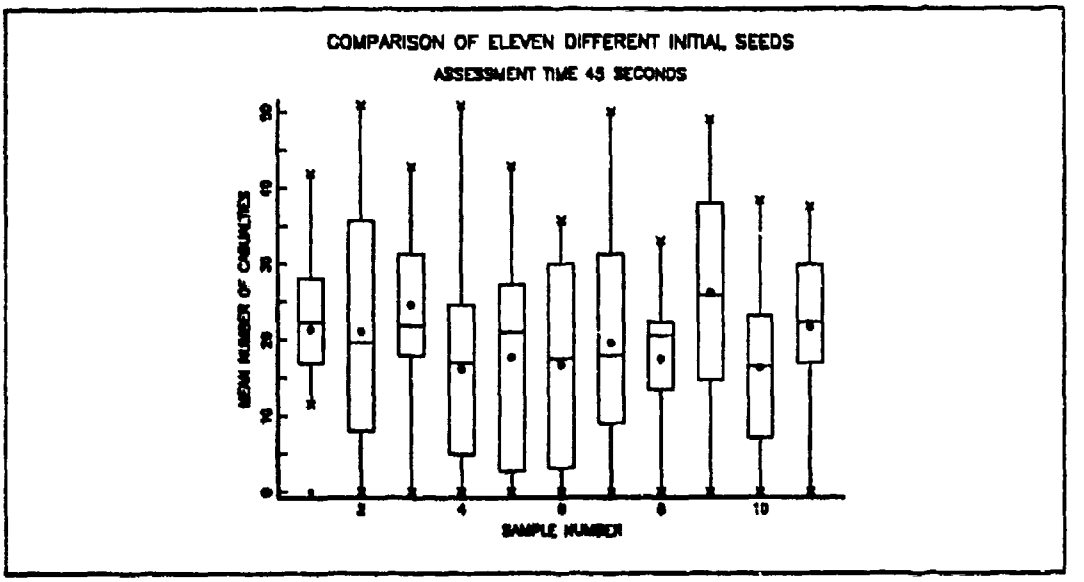

Figure 13. Comparison of Samples, Assessment Time 45 seconds.

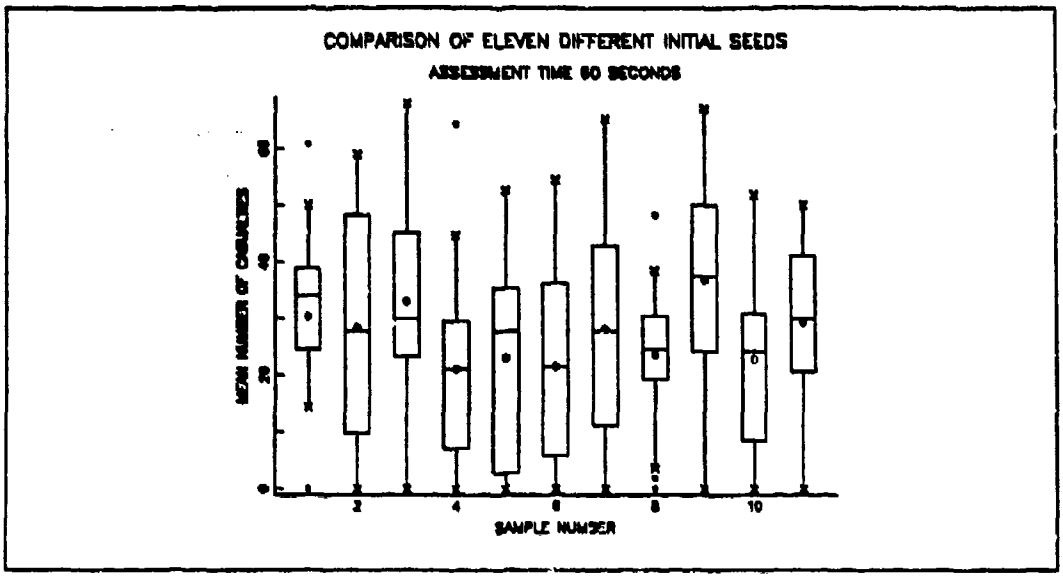

Figure 14. Comparison of Samples, Assessment Time 60 seconds.

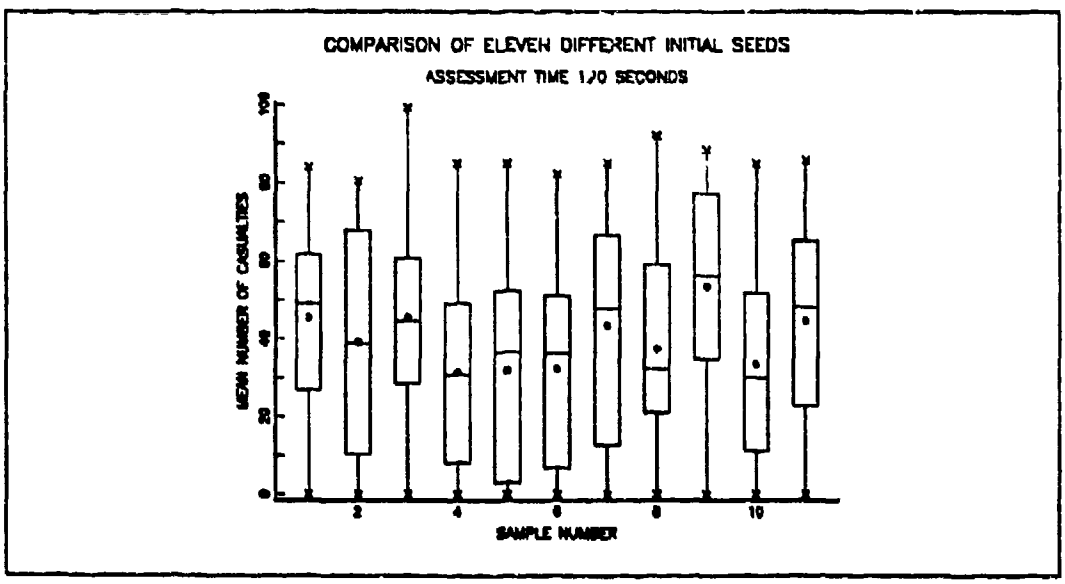

Figure 15. Comparison of Samples, Assessment Time 120 seconds.

In each of the five graphs above, the hypothesis that the samples came from the same population could not be rejected at a significance level of $\alpha = 0.05$. Since exper-

iment one demonstrated high variability in Appendix A, samples from other experiments gathered in this way should show an even closer relationship than the above graphs. On the evidence of this test, the selection of the initial starting seed does not matter.

The selection of an initial value for the simulation of the predicted casualties produced by a chemical attack does not influence the results. Therefore, the initial value of the random number seed should not have been variable. This fact alone saved a large amount of time and effort in producing this report.

APPENDIX D. SAS OUTPUT

PARAMETER ESTIMATES

VAR.	DF	PARAMETER ESTIMATE	STANDARD ERROR	T FOR H0: PARAMETER=0	PROB>|T|	VARIANCE INFLATION
X_0	1	18.70434230	0.10508882	177.986	0.0001	0
X_1	1	0.66273177	0.008232928	80.498	0.0001	1.00006980
X_2	1	0.01715192	0.000717552	23.903	0.0001	1.00002765
X_3	1	-1.62086786	0.01077922	-150.370	0.0001	1.00002991
X_4	1	-0.000117055	2.84099E-07	-412.020	0.0001	1.00000144
X_5	1	-0.10648600	0.000359302	-296.369	0.0001	1.00000015
X_6	1	50.04623864	0.10189702	491.145	0.0001	1.00009306
X_7	1	0.11899180	0.001127301	105.555	0.0001	1.00000001
X_8	1	0.22596822	0.000507840	444.960	0.0001	1.00000000

ANALYSIS OF VARIANCE

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PROB>F
MODEL	8	58326128.43	7290766.05	92224.709	0.0001
ERROR	233E3	18441091.42	79.05436774		
C TOTAL	233E3	76767219.84			

ROOT MSE	8.891252	R-SQUARE	0.7598
DEP MEAN	32.3918	ADJ R-SQ	0.7598
C.V.	27.44909		

MODEL CROSSPRODUCTS X'X X'Y Y'Y

X'X	X_0	X_1	X_2	X_3	X_4
X_0	233280	1166400	15731250	816480	16319100000
X_1	1166400	6998400	78610800	4082400	81564000000
X_2	15731250	78610800	1214381250	55036650	1.10065E+12
X_3	816480	4082400	55036650	3538080	57101100000
X_4	16319100000	81564000000	1.10065E+12	57101100000	2.12106E+15
X_5	17493300	87458400	1179702000	61222500	1.22370E+12
X_6	62960.72	314089.2	4249378	220005.3	4404470782
X_7	10497400	52486400	707895750	36740600	734342500000
X_8	12597120	62985600	849487500	44089920	881231400000
$\hat{Y}$	7556358	38522746	512360701	25328388	413968956697

X'X	X_5	X_6	X_7	X_8	$\hat{Y}$
X_0	17493300	62960.72	10497400	12597120	7556358
X_1	87458400	314089.2	52486400	62985600	38522746
X_2	1179702000	4249378	707895750	849487500	512360701
X_3	61222500	220005.3	36740600	44089920	25328388
X_4	1.22370E+12	4404470782	734342500000	881231400000	413968956697
X_5	1924155000	4721378	787183500	944638200	501440959
X_6	4721378	24607.21	2833182	3399879	2420645
X_7	787183500	2833182	534582000	566859600	347432574
X_8	944638200	3399879	566859600	986774400	477309365
$\hat{Y}$	501440959	2420645	347432574	477309365	321531235

X'X INVERSE, B, SSE

INVERSE	X_0	X_1	X_2	X_3	X_4
X_0	0.000139697	-0.000004329	-4.40267E-07	-.0000051803	-7.15722E-11
X_1	-0.000004329	8.57399E-07	2.51877E-10	5.12915E-11	2.75269E-14
X_2	-4.40267E-07	2.51877E-10	6.51299E-09	2.15894E-10	-1.13578E-15
X_3	-.0000051803	5.12915E-11	2.15894E-10	.00000146977	2.35945E-14
X_4	-7.15722E-11	2.75269E-14	-1.13578E-15	2.35945E-14	1.02097E-15
X_5	-1.22522E-07	1.13198E-11	-4.23937E-13	9.70271E-12	6.83224E-17
X_6	-.0000358827	8.03257E-08	-3.06168E-09	6.88506E-08	-3.07505E-15
X_7	-7.23413E-07	8.25404E-12	-3.09121E-13	7.07489E-12	4.98184E-17
X_8	-1.76166E-07	3.32218E-21	-1.28699E-22	2.84758E-21	-3.32044E-28
$\hat{Y}$	18.70434	0.6627318	0.01715192	-1.62087	-0.000117055

INVERSE	X_5	X_6	X_7	X_8	$\hat{Y}$
X_0	-1.22522E-07	-.0000358827	-7.23413E-07	-1.76166E-07	18.70434
X_1	1.13198E-11	8.03257E-08	8.25404E-12	3.32218E-21	0.6627318
X_2	-4.23937E-13	-3.06168E-09	-3.09121E-13	-1.28699E-22	0.01715192
X_3	9.70271E-12	6.88506E-08	7.07489E-12	2.84758E-21	-1.62087
X_4	6.83224E-17	-3.07505E-15	4.98184E-17	-3.32044E-28	-0.000117055
X_5	1.63303E-09	-9.72901E-12	2.41018E-16	-1.04032E-24	-0.106486
X_6	-9.72901E-12	0.00013134	-7.09404E-12	5.46625E-18	50.04624
X_7	2.41018E-16	-7.09404E-12	1.60751E-08	-3.42128E-24	0.1189918
X_8	-1.04032E-24	5.46625E-18	-3.42128E-24	3.26232E-09	0.2259682
$\hat{Y}$	-0.106486	50.04624	0.1189918	0.2259682	18441091

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