CHAPTER II

LITERATURE REVIEW

2.1 Literature on EPA's ISC Modeling

Atmospheric dispersion models based on the Gaussian approach have been used for assessing the impact of pollution sources on air quality for decades, and the U.S. Environmental Protection Agency (U.S. EPA) has conducted several studies to evaluate the performance of available regulatory models such as the Industrial Source Complex (ISC) model, for examples, works of Bowers et al. (1982), Schulman et al. (1985), etc. Some previous works on the evaluation of the ISC model had interesting conclusions. For example, Godbole and Naperkoski (1984) conducted studies to diagnostically evaluate the ISC model using specific point source field data and concluded in their study that the ISC model failed to reasonably predict the modeled sulfur dioxide impact. Also Riswadkar and Kumar (1994) found that the ISC model is a poor-performing model for sulfur dioxide in the 1-hour and 24-hour averaging periods under neutral and stable categories.

In mid 1995, the EPA upgraded the existing ISC2 model to the ISC3 model. It was investigated by Atkinson, D. G. et al. (1996) for its performance on the new area-source algorithm, dry-deposition and wet-deposition algorithm and the addition of a surface pit retention algorithm using source data from previous work of Doran and Horst (1985) and meteorological data from Doran et al. (1984) to estimate concentrations of ZnS tracer measured experimentally. Atkinson et al. found that, in a comparison using wind tunnel simulation results, the ISC3 model consistently tended to overestimate near-surface concentration values and to underestimate the concentration values aloft. Since, the comparisons were for near-surface releases, this result appeared to be simply related to an inability to appropriately characterize the vertical distribution of mass of a near-surface dispersion plume as having a Gaussian shape.

Taylor, R. K. (1996) tested the ISC short-term 3 (ISCST3) model performance using actual source parameters and emission rates to estimate hourly ground level concentrations for comparison to observed hourly ambient monitoring concentration data of pollutants from chemical manufacturing facility located in North Carolina, USA. for the year 1994. Their output indicated that within short transport distance (1 km), the model seemed to do the best in predicting concentrations during neutral and stable conditions and do the poorest during unstable conditions. For the wind speed categories, it appeared that the model slightly under-predicted concentrations for moderate wind speed categories (3-9 m/s) while over-predicting during periods of very light and strong winds. Although the model evaluation indicated some slight over- and under- prediction, it was noted that the absolute fractional bias in all cases was less than 0.5, thus, it could be pointed out that for the short-transport distance evaluations, the model performed relatively well for each meteorological category.

With respect to long-term prediction, both old versions, short-term (ISCST2) and long-term (ISCLT2), of the ISC2 model were evaluated by Patel and Kumar in 1998. They studied the performance of ISCST2 and ISCLT2 for mercury emissions using quarterly and annual averaging periods and they found that the ISCST2 model's predictions qualitatively match the observed concentrations values, while the ISCLT2 model's predictions are mostly slightly lower than the observed concentration. Their conclusion was that the ISCST2 model has a better overall performance than the ISCLT2 model.

Kumar, A., Bellam, N. K. and Sud, A. (1999) investigated the performance of the ISCST3 and ISCLT3 model for estimating monthly and quarterly concentrations of sulfur dioxide of Lucas County, Ohio, USA, for the year 1990. Besides, they estimated the uncertainties associated with the model's predictions by using the bootstrap re-sampling method as well as calculated the confidence intervals on the fractional mean bias, normalized mean square error, geometric mean bias and geometric variance for each model and differences between models. Intercomparison of the ISCST3 and ISCLT3 models indicated that these models yielded relatively good performance in their prediction of monthly and quarterly average concentrations, with relative fractional biases of 0.26 to 0.55 and normalized mean square error values that are about 0.12 to 0.44. Both the ISCST3 and ISCLT3 models predicted concentrations that are lower than the observed concentrations. Nevertheless, the concentrations predicted by the ISCST3 model were closer to the observed concentrations when compared with the concentrations obtained using the ISCLT3 model. Therefore, for this study, it can be pointed out that the ISCST3 model is better for estimating long-term concentrations of sulfur dioxide as compared to the ISCLT3 model.

Hoa, J. et al. (1999) employed the ISCST3 model to estimate the spatial and temporal distribution of vehicle emission and traffic-related pollutants (CO and NO_x) concentrations in Beijing, China, based on a limited database. The objective of their study was to assess the effectiveness of long-term control strategies and the contribution of vehicles relative to the total emission in Beijing. By treating vehicle sources as line sources, their study conducted substantial counting of vehicles on site to determine the traffic flow and vehicle type mixture. The total non-line-source vehicle-traveled mileage was distributed to different grids based on population density and road area in the grids. The obtained verification data showed that the ISCST3 model had good ability in simulating the pollutants impact from vehicles and indicated that overall mobile sources contributed 71% to CO concentration and 67% to NO_x concentration. Thus it could be pointed out that vehicle emissions are the most important air pollutant source in Beijing.

Hyde, P. et al. (1999) investigated the elevated PM_{10} concentration at two sites, Orange Grove and South Tucson, in Tucson metropolitan area, Arizona, USA, on four dates by using ISCST3 model. By comparing the predicted concentrations with measured total concentrations, it was found that the model under- predicted the local concentrations by about 25%, which is considered satisfactory in the kind of high-wind dispersion modeling due to high wind speed in the study area. Moreover, they concluded that the elevated PM_{10} concentration at both monitoring sites, were caused primarily from wind-blown emissions from cleared areas, construction sites, sand and gravel operations, and unpaved parking lots.

Koracin, D., Podnar, D., and Chow, J. (2000) employed a Gaussian dispersion model, ISCST3 model and an Eulerian-grid dispersion model, WYNDvalley, which are EPA-regulatory and EPA-alternative dispersion models, respectively, in order to simulate the PM_{10} impact in Treasure Valley, Idaho, USA. The ISCST3 model used the base-year meteorology and gridded emissions of mobile sources, point sources, and wood burning as input while the WYNDvalley model was evaluated using monitoring data and was used to simulate the PM_{10} concentration exceedances during stagnant winter conditions. An emission inventory was prepared for a base year (1995) and then extrapolated to the year 2000, 2005, 2010, and 2015 in order to determine air quality planning requirements. According to the results, the ISCST3 model was able to reproduce the correct order of magnitude of PM_{10} concentrations and also temporal variations at four of the six receptors whereas the WYNDvalley model results overestimated the measured data for all receptors. However, the annual exceedances of the 24-hr

PM_{10} NAAQS (National Ambient Air Quality Standard) concentration (150 μ g/m^3) can be expected for years 2000, 2005, 2010, and 2015.

Lorber, M., Eschenroeder, A., and Robinson, R. (2000) examined the performance of the ISCST3 model in predicting polychlorinated dibenzodioxins and polychlorinated dibenzofurans concentrations in both air and soil near the Columbus Municipal Solid Waste-to-Energy (CMSWTE) Facility in Columbus, Ohio, USA. In order to predict such concentrations after 11 years of operation of the CMSWTE, predicted annual average dry and wet deposition of particle bound dioxins obtained from ISCST3 were input into a simple soil reservoir model to further predict soil concentrations that would represent 11 years of emissions, and then were compared to measured concentrations. According to the results, predicted and measured dioxin elevations in air and soil appeared to generally be within a factor of 10 of each other. In addition, the ISCST3 correctly identified the north/northeast quadrant in their study area as being the area with elevated soil concentrations.

Mazzeo, N. A. and Venegas, L. D. (2000) presented an objective methodology for selecting the minimum number of sampling sites required to register the highest concentration values of air pollutants emitted from a continuous point source in Buenos Aires, Argentina. Their methodology was based on the analysis of one-hour concentration values above a threshold value estimated by ISCST3. The number and location of the air monitoring stations were determined according to the likelihood that a station could measure high concentration values in accordance with model results. The ISCST3 was applied to a point source emission and meteorological data of year 1995. As indicated by their results, the approximated value of the designed network efficiency is 0.475 at best.

In short, there are many efforts in the atmospheric model improvement for the environmental impact assessment. In addition, several studies employed the ISC model in order to assess the environmental impacts from various pollutants, which are seemingly a conventional method in the attempt of finding the best efficacy of pollution control strategy. As one can see, the reliability of any modeling results is strongly influenced by the model inputs. In modeling the phenomena of atmospheric dispersion, it is almost impossible to avoid uncertainties in specifying input parameters and uncertainties due to deficiencies in model physics and chemistry assumptions, or uncertainties due to natural or stochastic fluctuations in the atmosphere. Consequently, stochastic studies of such uncertain inputs have employed the Monte-Carlo technique as a tool for determining the uncertainty in model outputs. Some simulation studies concerned with uncertain inputs conducted by using Monte-Carlo approach are demonstrated in the following section.

2.2 Literature on Stochastic Modeling

Hanna, S. R. et al. (1998) studied and estimated uncertainties in predictions of ozone in New York, USA, by photochemical grid model, UAM-IV, due to uncertainties in input variables such as meteorological conditions, variables related to emissions, etc., via Monte-Carlo method. At the first step, their study asked ten modeling experts to estimate the typical uncertainty of 109 UAM-IV model input parameters, including 23 variables related to emissions, boundary conditions, and meteorological conditions, and 86 variables related to chemical kinetics rate constants. For many of the model inputs, the assumed range of uncertainty was about plus or minus 30% of a normal mid-range value, and, in most cases, the distributions were assumed to have a log-normal shape. Next 50 Monte-Carlo UAM-IV runs were carried out by simple random sampling of each of the 109 input parameters from the assumed distributions. In accordance with the 50 predicted values of peak hourly averaged ozone concentrations anywhere on the geographic domain, they were found to follow a log-normal distribution and exhibit a variability from 176 to 331 ppb. Besides, it was found that the variability in the input parameter known as the anthropogenic volatile organic compound (VOC) area source emissions had the most influence on the variations in the 50 predicted peak zone concentrations.

Blackman A. et al. (1999) proposed a benefit-cost analysis of four practical strategies in combination with benefits transfer methods and Monte-Carlo technique for reducing PM_{10} emissions from traditional brick kilns in Ciudad Juarez, Mexico. Their methodology firstly used a specially parameterized ISCST3 model to estimate all brick kilns' combined contribution to annual average ambient levels of PM_{10} at several hundred receptor locations in Paso del Norte and then used a health effects models to estimate the number of cases of human mortality and morbidity that result from PM_{10} each year. For the meteorological data, available data of year 1990 was used. The probability distributions for several of the emissions source characteristics were used to perform a Monte Carlo analysis that accounts for uncertainty associated with the parameterization of air dispersion, health impacts, and benefits valuation models. The estimates obtained from both kinds of model showed that the benefits of three out of four control strategies were considerably higher than the costs.

Chan, T. L. et al. (2001) applied Monte-Carlo technique to simulate the pollutant dispersion behavior from the vehicular exhaust plume, particularly NO and NO_2 corporate with two-dimensional pollutant dispersion numerical model, which was developed based on the joint-scalar probability density function (PDF) approach coupled with a k-ε turbulence model. The simulated variables were the initial dispersion process of nitrogen oxides, temperature and flow velocity distributions from a vehicular exhaust plume. The numerical model was validated by comparing the measured and calculated nitrogen oxides data by simulating the vehicle situations included vehicles at both low idling and high idling. A Monte-Carlo algorithm was used to solve the PDF transport equation for obtaining the thermodynamic parameters (i.e. temperature and concentrations of chemical species) and nine sensitivity cases were also performed to investigate the effects of different exhaust exit velocity and wind speeds on the initial dispersion of NO and NO_2 from the exhaust plume. The good agreement between calculated and measured data indicated that the joint-scalar PDF approach can be used to solve the initial pollutant distribution emitted from the vehicular exhaust tailpipe and Monte-Carlo method was shown to be useful for predicting the initial dispersion of exhaust pollutants for a typical vehicular exhaust plume.

Moore, G. E. and Londergan, R. J. (2001) developed and tested a method of quantifying the uncertainties in concentration predictions by a complex photochemical grid model (PGM) using a modification of the basic Monte-Carlo method (MCM). The sampling approach to the MCM was explored as an efficient approach to assess the uncertainty in the differences in predicted maximum ozone concentration between base case and control scenarios. The uncertainty in model inputs and parameters such as meteorological parameters were simulated using several types of stochastic models, which were driven using Latin hypercube sampling (LHS) to generate a non-redundant ensemble of alternative model inputs. One hundred alternative concentration estimates were generated for a base scenario and for control scenarios representing 50%, 10% and 5% reduction of NO_x emissions. Their study demonstrated that sampled MCM could be implemented within a PGM with relatively little modification using the multipliers to track the history of uncertainty. Perturbations in hundreds of input variables and results from 10% and 5% NO_x emission controls indicated that when the concentration differences decrease in magnitude due to smaller emission controls, the confidence ranges also decline.

Winiwarter, W. and Rypdal, K. (2001) studied and determined the uncertainty of Austria's Greenhouse Gas (GHG) emission inventory for the gases CO_2, CH_4 and N_2O. Their study conducted under uncertainties in inventory input data based on expert interviews and literatures combined with the using of Monte-Carlo analysis in which an appropriate probability density function (PDF) was chosen for each of the uncertainty parameters according to the information available. Their results for all sources and gases combined indicated an overall uncertainty between 10.5% and 12 depending on the base year considered. Moreover, they also concluded that there is a difference whether natural sources and land use change and forestry are considered or not, especially land use change is not only a major contributor, but also considerably uncertain.