Philadelphia Air Toxics Study: Evaluation of Risk Management Options Using MIRA

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Abstract: Evaluation of risk management options usually takes place within single programs at the U.S. EPA. This can produce inadvertent tradeoffs among important criteria by risk managers and other decision makers; resulting in decision surprises. This study is a demonstration of a different approach to risk management and decision analysis. In this study, the use of the Multi-criteria Integrated Resource Assessment (MIRA) approach shows how risk managers can examine the impacts of different control strategies on cancer risk, pollutant hazard, and ozone and particulate matter in a "one atmosphere" approach to risk analysis.

Methodology:

The study domain is a 370x316 km grid centered around Philadelphia County, PA. Three control scenarios were examined in this study: 1) 30% reduction in aromatic emissions, 2) 30% reduction in olefin emissions, and 3) 30% reduction in nitrogen oxide (NOx) emissions. The Community Multiscale Air Quality Model (CMAQ), with SAPRAC '99 chemistry, was run, on a 4km resolved grid for the 2001 baseyear, examining hazardous pollutants (acetaldehyde, acrolein, benzene, and formaldehyde), cancer-causing pollutants (acetaldehyde, benzene and formaldehyde), and 2 criteria pollutants (ozone and fine particulate matter (PM2.5)). The resultant concentration fields of the pollutants were examined using several variations of the Fractional Improvement Indicator (FII), a metric which has the form of a normalized residual (i.e., [control – base]/base). In this study, the mean change of the FII is used to assess the average change across the study domain. In addition, the FIIs representing the greatest degradation and the greatest improvement in the study domain is used to assess the range of air quality impacts due to the hypothetical implementation of the 3 control scenarios. The risk management question for this study is "Which of the 3 control strategies is the most attractive air quality management option, considering hazardous and cancer-causing pollutants as well as ozone and PM2.5?"

Figure 1:
Study Domain

MIRA Methodology:

For this study, all air quality data is indexed to place them on the same decision scale and criteria are weighted using the normalized hazard quotient or unit risk. Ozone and PM2.5 are weighted separately against the hazardous/cancer pollutants since they have neither a hazard quotient nor unit risk.

Compound	Reference Concentration (mg/m^3)	Unit Risk (mg/m^3)$^{-1}$	Normalized Hazard	Normalized Risk
Acetaldehyde	9×10^{-3}	2.2×10^{-6}	0.002	0.096
Acrolein	2×10^{-5}	0	0.997	N/A
Benzene	3×10^{-2}	7.8×10^{-6}	0.0007	0.339
Formaldehyde	0	1.3×10^{-5}	0	0.56
Ozone	0	0	N/A	N/A
PM2.5	0	0	N/A	N/A

Results:

In order to analyze the impacts of pollutants, risk managers are typically presented with a series of maps for each one pollutant. An example using acrolein is shown in the figures below. Figure 2a represents the base case. Figure 2b represents the control case and figure 2c represents the FII.

Figure 2a:
Acrolein Concentrations - Base Case

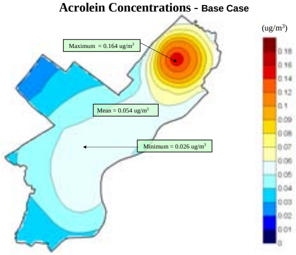


Figure 2b:
Acrolein Concentrations- 30% Olefin Control Case

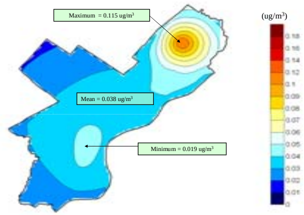
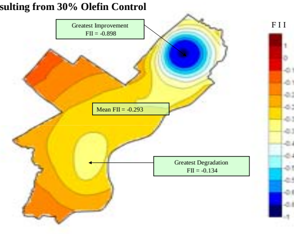
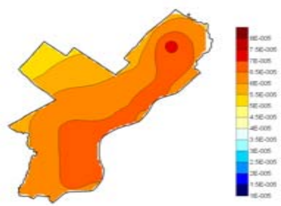


Figure 2c:
Fractional Improvement Indicator (FII) -- Change in Acrolein Concentrations Resulting from 30% Olefin Control



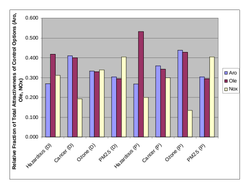
In this case study, some pollutants are hazardous (as with acrolein) and some are cancerous (such as benzene). The cancer-causing pollutants can be analyzed using risk as shown in Figure 3 for total risk for formaldehyde, benzene, and acetaldehyde as a result of applying a control strategy reducing 30% of aromatic emissions.

Figure 3: Concentration Normalized by Unit Risk
Total (Formaldehyde + Benzene + Acetaldehyde)
30% Aromatics Control Case



Alternatively, shown in Figure 4 is a comparison among groupings of pollutants by type (hazardous vs. cancer vs. ozone vs. PM2.5). However, what risk managers need is a means to evaluate all pollutants together against different control scenarios. Figure 5 shows how MIRA allows risk managers to examine all pollutants at the same time.

Figure 4:
Comparison of the Impacts of three control scenarios (Aro, Ole, NOx) on four groups of pollutants (hazardous, cancer, ozone, PM2.5) between Philadelphia and Entire Domain



D = Domain wide P = Philadelphia

MIRA Results:

Among the results for this study, we find that the 30% aromatic control strategy is the most attractive option among the 3 options when cancerous compounds are of most concern in either the domain or Philadelphia or when ozone in Philadelphia is most important. When hazardous compounds are of most concern (either D or P), the 30% olefin control strategy is looks the most attractive. When PM2.5 is of most concern (either D or P) or ozone in the domain is of most concern, the 30% NOx control strategy is the most favored.

The most significant results lie in the analyses of the impacts of the 3 control scenarios when all pollutants are considered together in different weighting combinations. Figures 5 and 6 show two possible combinations. In Figure 5, the result shown is for the weighting of cancer pollutants being twice as important to the risk manager as hazardous pollutants and ozone being weighted equally against the cancer/hazardous pollutants and PM2.5 is ignored. Therefore, hazardous/cancer compounds and ozone are each 50% of the total decision weight.

Figure 5:
Comparison of the Impacts of three control scenarios (Aro, Ole, NOx) on all air pollutants between Philadelphia and Entire Domain when PM2.5 is ignored.

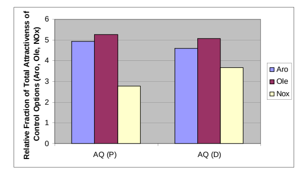


Figure 6:
Comparison of the impacts of three control scenarios on all air pollutants between Philadelphia and Entire Domain when PM2.5 is weighted most heavily.

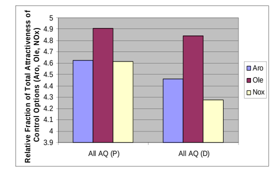


Figure 6 shows the same weighting between hazardous and cancer compounds as used in Figure 5 but the weighting of PM2.5 as 50% of the overall decision with ozone being 5% and hazardous/cancer compounds at 45% of the total decision weight.

Conclusion:

This study demonstrates the use of hazard quotients and unit risk in an integrated risk management scenario where other pollutants such as ozone and PM2.5 also need to be considered. The relative importance of each of the hazardous and cancer-causing pollutants is considered through the use of the normalized hazard quotients and unit risks. This study further shows how these compounds can be considered with other, such as ozone and PM2.5 (which do not have a hazard quotient or unit risk), in a "one atmosphere" analytical approach to risk management. The relative attractiveness of the decision options can change depending on what is of most concern to risk managers. Risk management decision making requires a determination of the relative importance of the decision criteria, in this case, the air quality impacts of 6 compounds. In addition, when the decision criteria are disparate (in this case, some hazardous, some cancerous and others criteria pollutants), the analyst must devise an approach that allows for comparisons between and among these disparate criteria. Future work in this study will demonstrate how decision makers can integrate economic and social criteria with the above risk criteria. MIRA is an approach that provides for the use of scientific data (hazard quotients, unit risk, air quality modeling results) in a framework that allows risk managers and other decision makers to examine the impacts of judgments made about that data and to learn how the attractiveness of different options can change depending on how these judgments are made.

References: 1) (MIRA) Stahl, C.H., A.J. Cimorelli, and A.H. Chow (2002) Bull. Sci. Tech. Soc. 22(6): 443-456. **2)** (FII) Cimorelli, A.J. and C.H. Stahl (2005) Bull. Sci. Tech. Soc. 25(1): 46-52. **3)** (Uncertainty) Stahl, C.H. and A.J. Cimorelli (2005) Risk Analysis 25(5): 1109-1120.