MIRA – An Approach to Multi-Criteria Decision Making

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Outline

- Nature of Decision Making
- What is MIRA
- What MIRA is NOT
- The MIRA Approach
  - Methodology
  - Output
- Previous Applications
- Examples and Demonstration:
  - Philadelphia Multi-Pollutant Control Strategy Analysis
- Conclusions

Nature of Decision Making

- Using the same data - There is no “Right” answer just different perspectives
- All decisions are value judgments
  - Science cannot make decisions
  - Science can only inform or constrain
  - Stakeholders have many varied points of view
- Decisions are tradeoffs among varied criteria
  - Explicit & implicit
  - Scientific, socio-political & economic
- Context is paramount
  - What is the question and what are the constraints?

What is MIRA? (Multi-Criteria Resource Assessment)

- An analytical decision support framework designed to rank elements of environmental sets

  For example: control options, emission sources, other decision options, geographical areas, etc.
- A large # of highly diverse criteria can be included
  - Both quantitative and qualitative information
  - Environmental, social, political, and economic data
  - Encourages the inclusion of stakeholder concerns (if consensus can't be reached include the criterion)
- Both expert opinions and value judgments are explicitly included
  - Value judgments are transparency
  - Scientific data are explicitly separated from value judgments
- MIRA is designed as an iterative improvement and learning process
- MIRA explicitly reviles the rationale or justification for a decision

What MIRA Is Not!

- MIRA is not a once through analysis – MIRA's underlying philosophy is to learn about the relationship between science, policy and values **WITHIN THE DECISION CONTEXT**
  - How sensitive is the data & value judgments to the final decision?
  - How robust is the decision? Do the decision options change rank with small changes in data or values?
  - That is, MIRA can help determine the degree of confidence one should have in a decision
- MIRA is not an optimization approach – MIRA stresses learning (informed people decide what is optimal)
- MIRA is not a black box - decision makers are still responsible for the decision.

MIRA: General Approach

- Define the decision question
  - Sets the decision context
- Establish problem set:
  - Items that are to be evaluated (i.e. ranked)
  - Eg.: Control options, source sectors, geographic areas, etc.
- Establish decision criteria
  - Environmental, Social, political, economic, etc.
  - Quantitative and/or qualitative
  - Be as inclusive as you like
- Construct decision hierarchy
  - Primary means to organize data consistent with the decision context or decision question.

MIRA: General Approach

- Index criteria
  - Purpose:
    - Allow comparisons among varied criteria
    - Add insight to the data (establishes decision context quantitatively)
  - Method:
    - Place criteria metrics on same scale
    - MIRA uses a decision scale of 1 to 8.
    - Converts data units (e.g., ppm, tons per year or # of people) into decision units (e.g., vulnerability, attractiveness, etc.).
  - The basic question: How much does each criterion have to change to elicits the same response?
    - E.g. 10 $\mu g/m^3$ increase in SO_2 is as significant as an a 1% increase in cancer risk, or $1,000,000 spent
  - Requires expert input & collaboration of

MIRA: General Approach

- Establish preferences (value set)
  - Define relative importance among all criteria within the decision hierarchy
    - Criteria are weighted within each hierarchy cluster s.t. the sum of the weights = 1.0
    - These sets of weights (value judgments) for the entire hierarchy defines a “value set” for the decision
    - Can develop multiple “value sets”
    - Each value set represents a different perspective
  - This is typically where decision or policy makers play - not scientists.
- Science (data & indexing) and values (preferences) are dealt with separately

MIRA: General Approach

- Decision Analysis using MIRA
  - Calculate “criteria sum” (decision index) for each Problem set element

    i.e., the hierarchy collapses to a single value via this series of weighted linear sums of the clusters - ∑(values=pref x science=indexed data)
  - Rank problem set elements
  - Determine decision drivers – What criteria are most important?
  - Perform sensitivity
  - Learn
  - Re-evaluate:

    Criteria, hierarchy, indexing, value set, problem set and even the decision question.
  - Iterate

MIRA Output

- Ranked Problem Set
- GIS Map if problem set elements are spatial
- Criteria Ranking:

  Can be viewed at any level of the hierarchy

  - Value Set:

    CAN YOU ACCEPT THE VALUE SET THAT JUSTIFYS YOUR DECISION????

Previous and Current Applications

- 8 hour ozone nonattainment designations boundaries
- Preliminary PM2.5 nonattainment designations boundaries
- Preliminary Ozone and PM2.5 Monitoring Network Assessment
- Assessment of the Impacts of Data Uncertainty
  - The amount of acceptable uncertainty is judged on how it impacts the rankings
- Region 3 2009 & 2010 Budgetary Analysis
  - Considered all regional programs
  - Evaluated the environmental condition of the region – based on a large set of multi-media indicators
  - Re-directed resources to important regional problems

Philadelphia Multi-Pollutant Control Strategy Analysis - Using MIRA

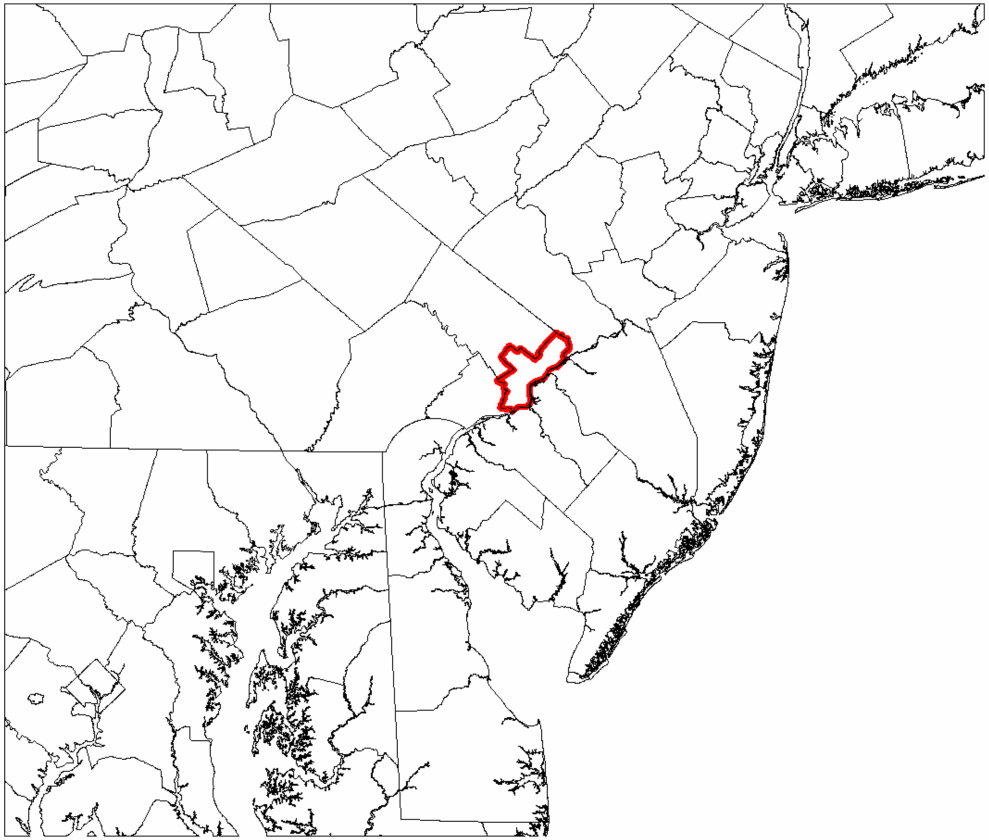
- Explore linkages between air toxics, O_3 & $PM_{2.5}$
- Perform "One Atmosphere" analysis
  - CMAQ (4 km) & ISCST models
  - Link based mobile emissions '96 NEI Stationary emission
  - 2001 Met – Philly NWS & MM5
- Examine attractiveness (the decision unit) of various control strategies using MIRA

One Atmosphere: Planning Example

- Decision question: What is the most attractive control option?

  It will depend on:
  - The criteria chosen
  - The relative value given to the 3 programs – at present this depends on which program is doing the analysis (stove piped)
  - The variability in spatial impacts and how we value different areas
  - The relative value given to the set of environmental metrics used
- Problem Set: Three example control scenarios:
  - 30% reduction in aromatic emissions
  - 30% reduction in olefin emissions
  - 30% reduction in NO_x emissions
- Criteria:
  - Consider two impact areas: Philadelphia & a broader domain
  - Consider 4 toxics pollutants, O_3 & $PM_{2.5}$
  - Consider 3 environmental metrics
    - The mean spatial change in concentration

Extended Domain



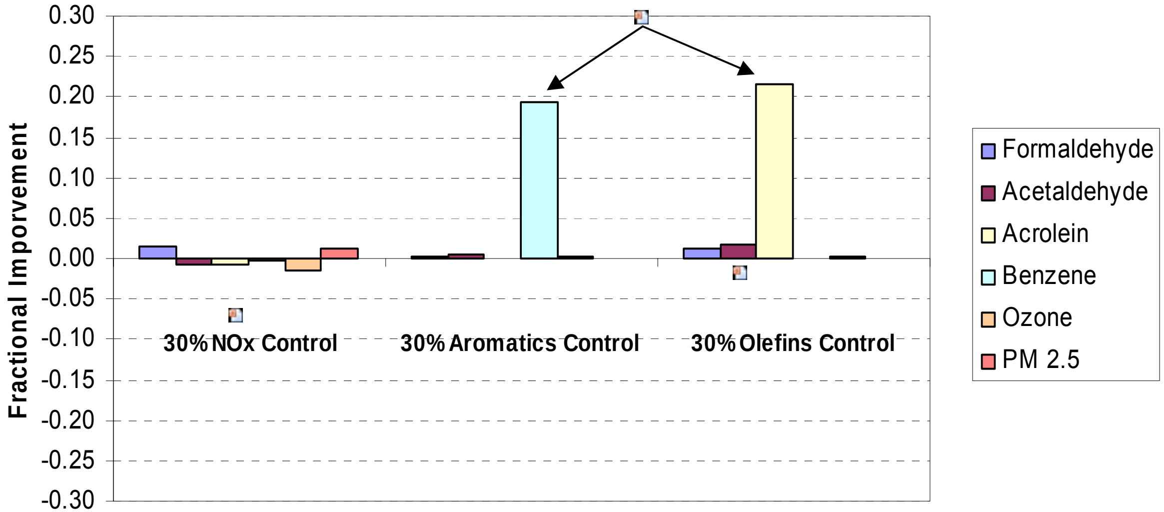
One Atmosphere: Evaluation Criteria

- Evaluation criteria:
  - Estimate concentration fields for the 2001 baseline and 3 control cases for:
    - Air Toxics: formaldehyde, acetaldehyde, benzene and acrolein
    - Ozone
    - $PM_{2.5}$
  - Use fractional improvement metrics to evaluate control scenarios

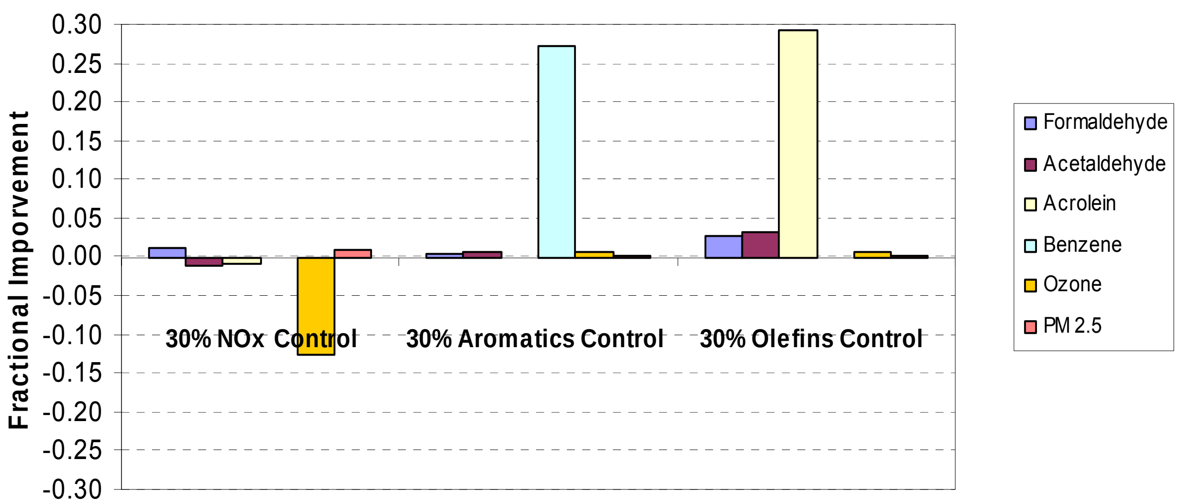
$$FII = \left(\frac{\chi_{Base} - \chi_{Control}}{\chi_{Base}} \right)$$

    - Three metrics: Mean, maximum & minimum
    - Two areas: Domain wide & Philadelphia

Domain Wide FII (mean)
Control Strategies



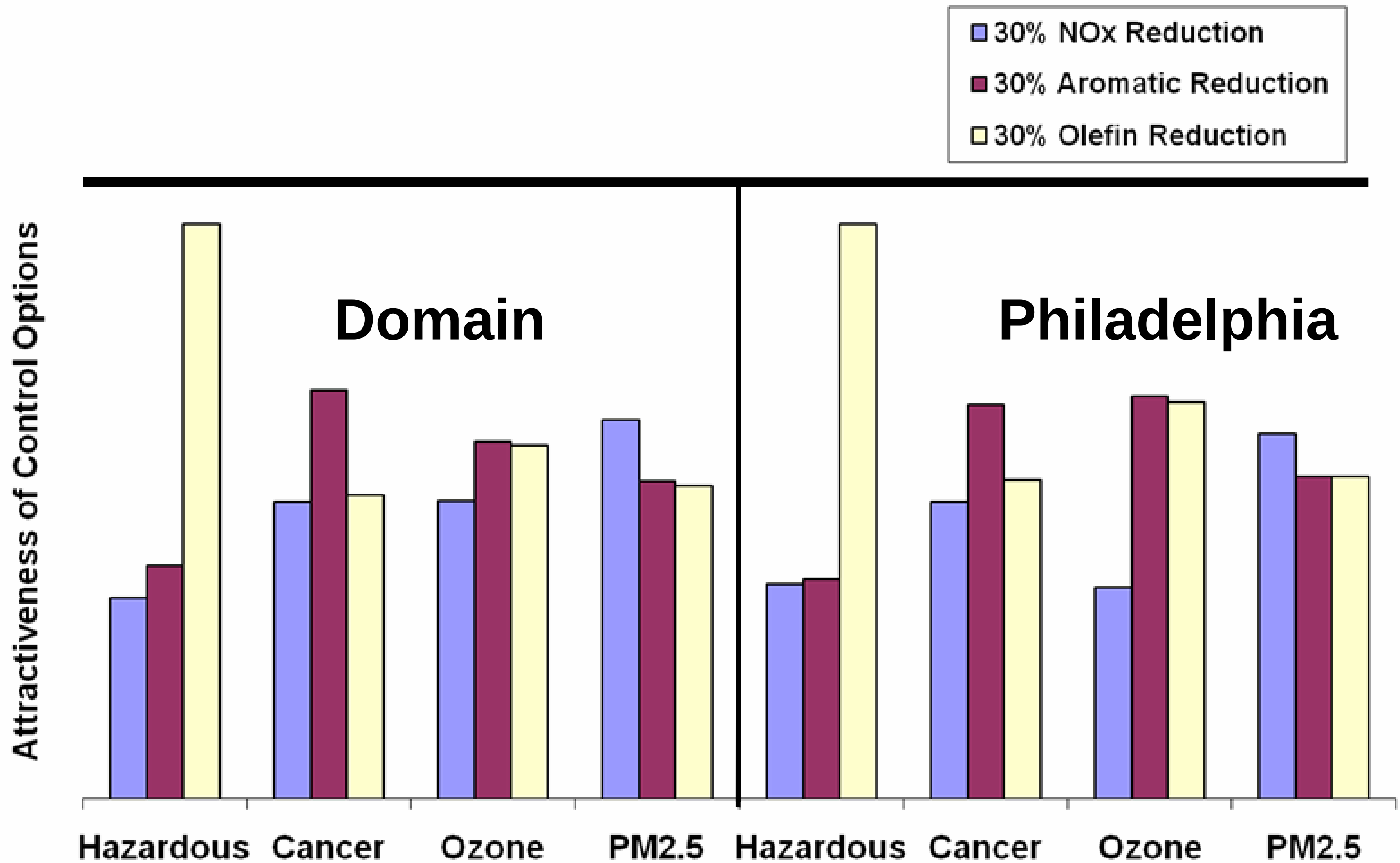
Philadelphia FII (mean)
Control Strategies



Attractiveness of Control Options (by Pollutant)

- Index criteria:
  - Convert FII's to the same decision units (i.e., attractiveness)
- Combine air toxics into two composite pollutants
  - Carcinogenic toxics – combine based on unit risk
  - Hazardous (non-cancer) toxics – combine based on reference concentrations
- Compare relative attractiveness among control options for each pollutant and area:
  - 4 Pollutants: Hazardous, cancer, $PM_{2.5}$ & O_3
  - 2 Areas: Domain & Philadelphia
  - Assume FII_{mean}, FII_{MaxDeg} & FII_{MaxImp} are of equal importance

Analysis of Control Scenarios



Conclusions Base on FII Comparisons

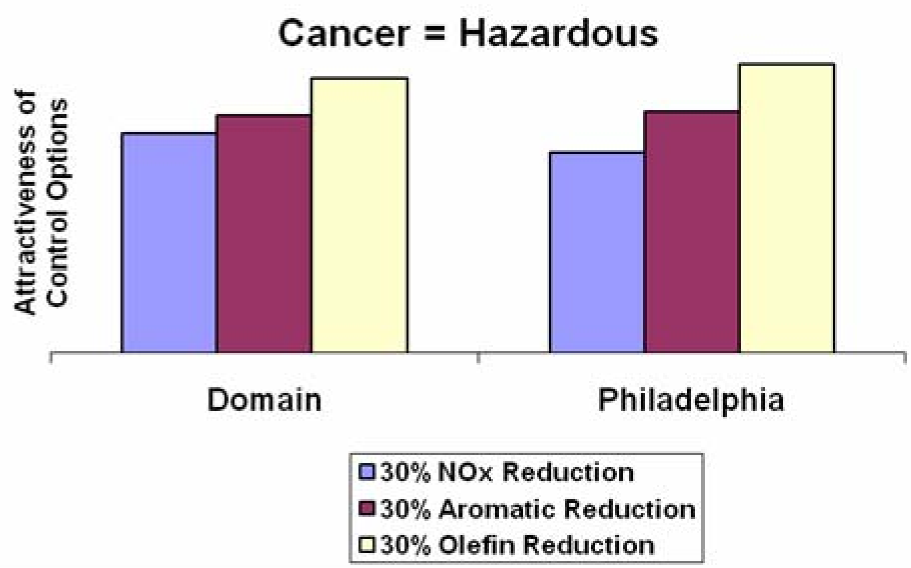
- Difficult to select option since different control strategies effect different pollutants
- The strategy chosen will depend on the relative importance we place on the various programs (i.e. Air Toxics vs. O_3 vs. $PM_{2.5}$)
- It seems clear that NO_x is lest preferred. However, it could be chosen if we are willing to accept certain value sets
- A decision framework is needed to systematically examine the viability of the control options relative to the value sets they imply

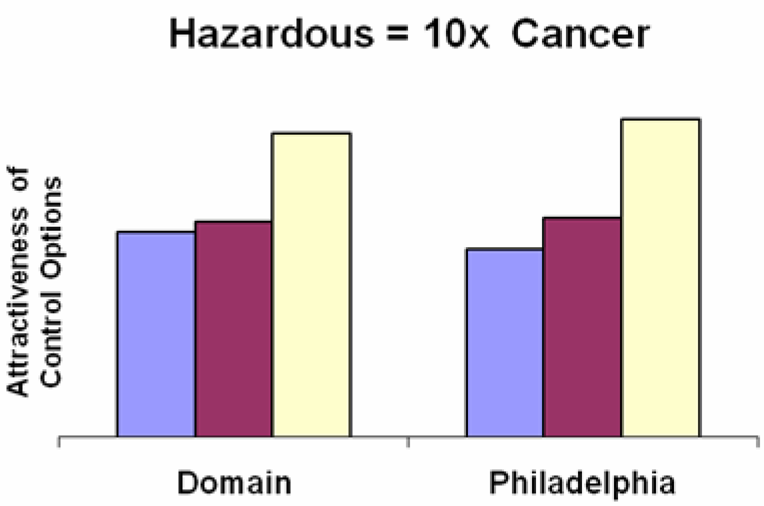
Selecting a Control Option Using MIRA (There is no "RIGHT" Answer)

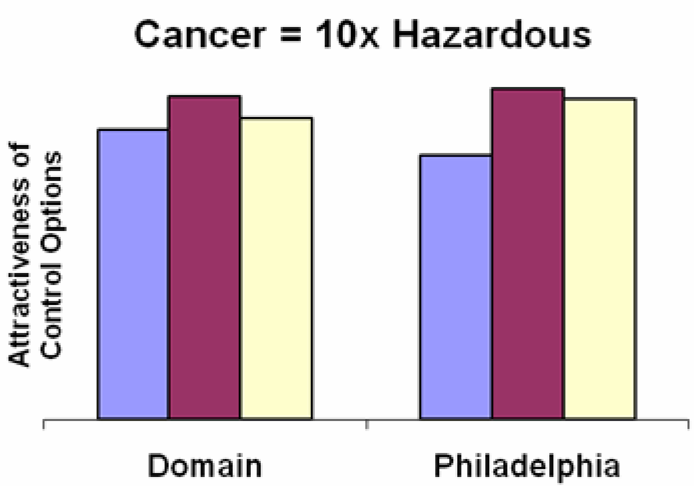
- Depends on **value judgments** (value set) regarding
  - Cancer vs. Hazardous effects
  - Air Toxics vs. O_3 vs. $PM_{2.5}$ programs
  - Geographic area

- Example 1: *Vary the importance of Haz vs. Cancer*
  - 2 Areas – evaluated separately
  - 3 FII's - equally weighted
  - 3 Programs – equally weighted
  - Value Sets:
    - Equally weighted
    - Cancer = 10x Hazardous
    - Hazardous = 10x Cancer

Sensitivity To Composite Toxic Pollutants Weighting
Equal Program Weighting



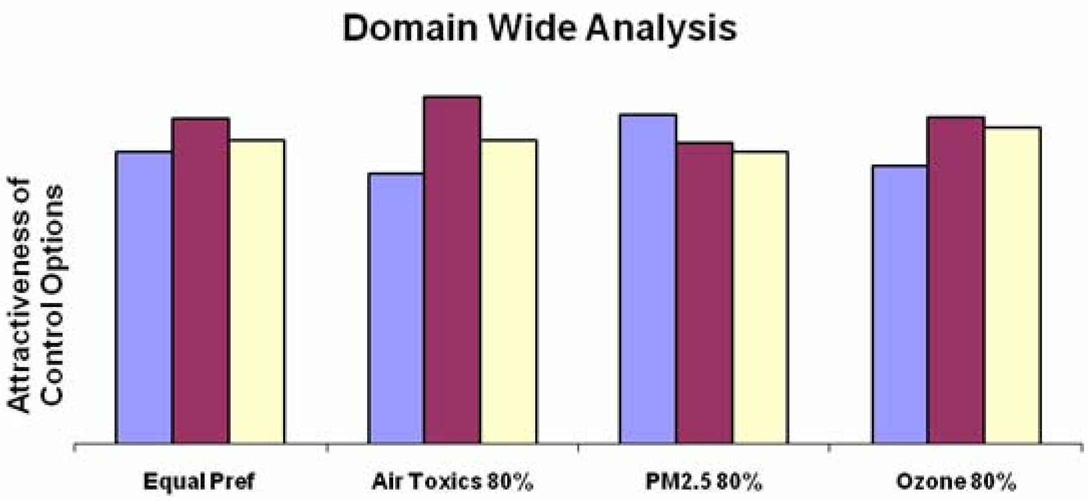


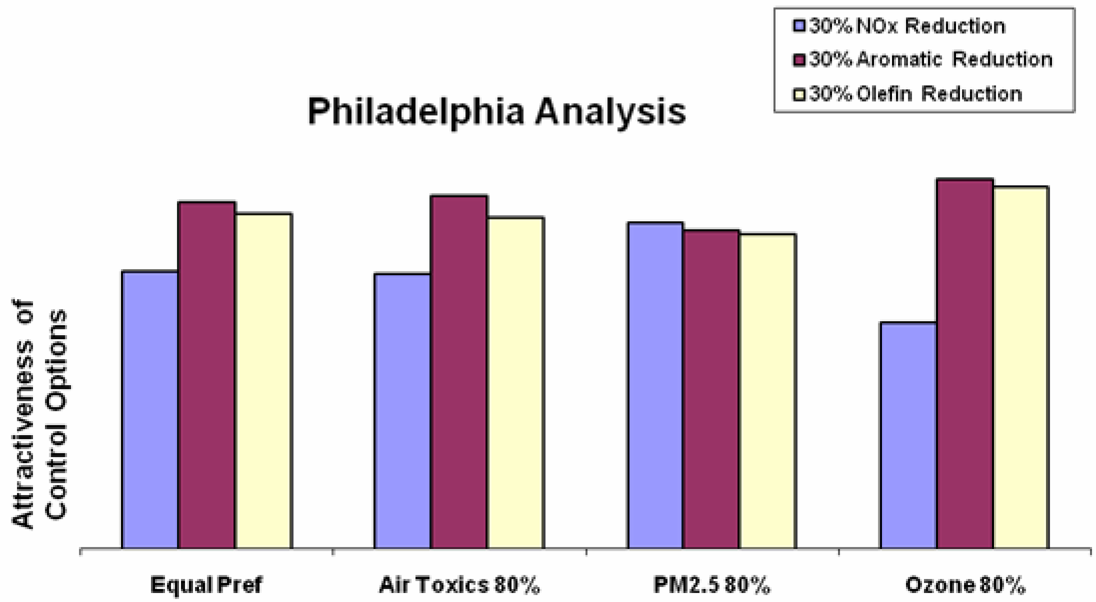


Selecting a Control Option Using MIRA (There is no “RIGHT” Answer)

- Example 2: *Vary the Importance of the programs*
  - 2 Areas – evaluated separately
  - 3 FII’s - equally weighted
  - Cancer = 10x Hazardous
  - Value Sets:
    - The 3 programs are equally weighted
    - Air Toxics accounts for 80% of the decision, Ozone 10% & PM2.5 10%
    - Ozone accounts for 80% of the decision, Air Toxics10% & PM2.5 10%
    - PM2.5 accounts for 80% of the decision, Ozone 10% & Air Toxics10%

Sensitivity To Program Weighting
Cancer 10x Hazardous



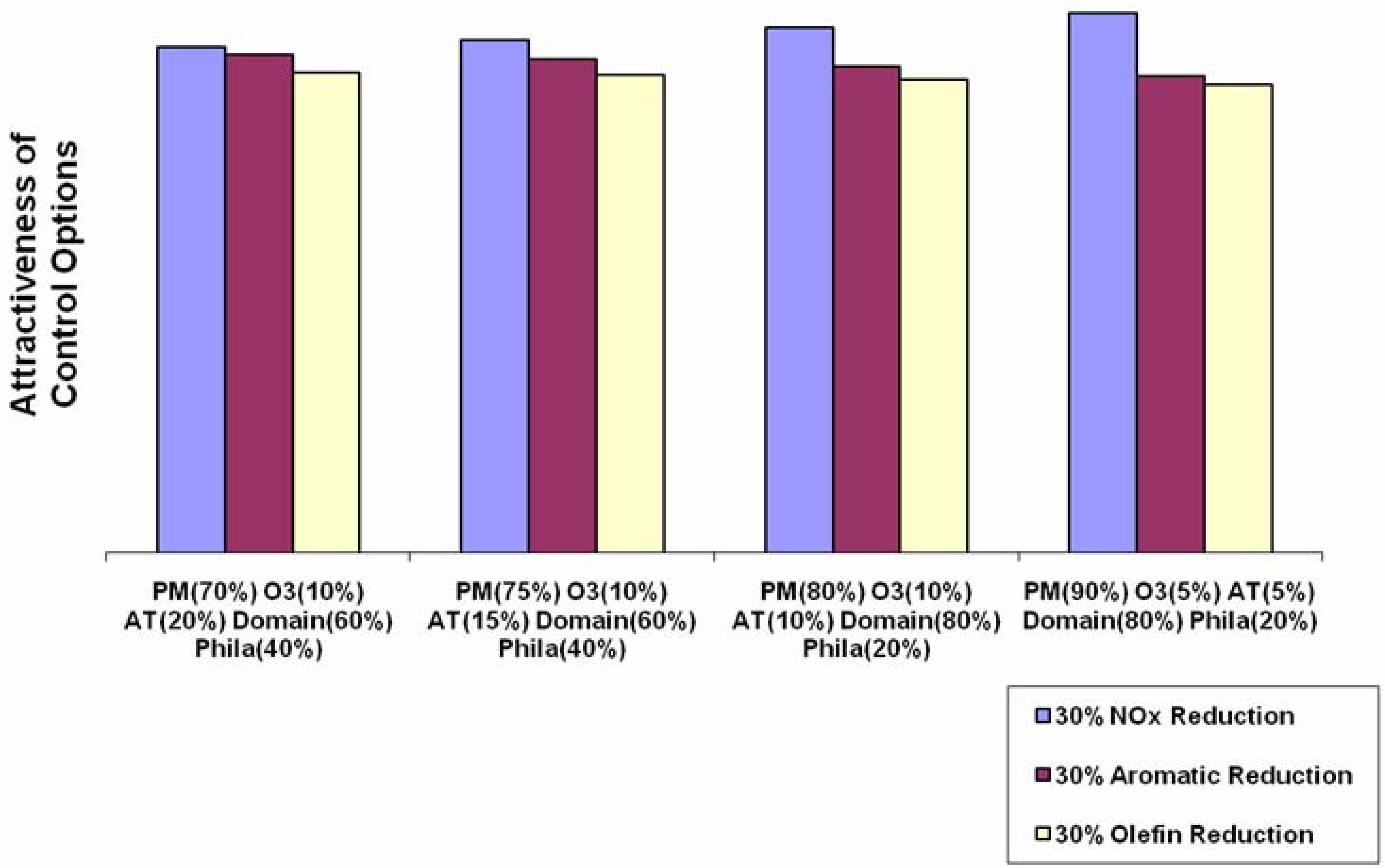


Selecting a Control Option Using MIRA (There is no "RIGHT" Answer)

- Example 3: *What value sets will justify selecting the 30% NOx reduction strategy?*
- Hold Constant:
  - Cancer = 10x Hazardous
  - 3 FII's - equally weighted
- Vary:
  - Importance of areas (Philly vs. Domain)
  - Importance of the 3 Programs (Air Toxics, O3 & PM2.5)
- Four example value sets:

BACKCASTING

What Value Sets will justify
30% NO_x Reduction Strategy?



CONCLUSIONS – One Atmosphere Example:

MIRA can support multi-pollutant decision making by providing decision makers the ability to:

- Better understand how the various decision criteria interrelate
- Examine the policy implications of stove piped decision making – what is the impact of their decision on other programs
- Become less vulnerable to causing inadvertent adverse effects to the environment and/or other programs
- Uncovering the value sets that are implied by a decisions

GENERAL CONCLUSIONS

- There is no "RIGHT" answer in decision making
  - Decisions, by their nature, are value judgments
  - Science should inform/constrain the decision not make decisions
- MIRA provides a decision framework which:
  - Separates the objective science from the subjective decision making
  - Allows the science to inform the decision
  - Provides a learning mechanism for scientists
    - Forces scientific thinking within context
    - Forces collaboration among relevant disciplines
  - Provides a learning mechanism for decision makers (connects value sets to decision options)
  - Facilitates stakeholder participation
    - Provides a mechanism for including stakeholder interests
    - Consensus building is a natural result of the process
  - The justification for a decision is well defined and transparent