Simple Interactive Model for Better Air Quality
(SIM-AIR version 1.1)

User manual for SIM-AIR version 1.1

by

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Note: The current spreadsheet and manual is still under developmental stage. Any suggestions on improvisation of the spreadsheet as well as the manual are most welcome. Please send your queries/ comments/suggestions/critiques to: prashant.rajurkar@emcentre.com

Note

SIM-BAQ is now known as SIM-AIR

About SIM-AIR

SIM-AIR is the outcome of efforts by:

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INTRODUCTION

Getting started

SIM-AIR uses a Microsoft® Excel spreadsheet with Visual Basic macros to facilitate the development of an integrated interactive decision support system for Urban Air Quality Management (UAQM). The spreadsheet allows computation of an emission inventory for key pollutants, estimates impact of emissions sources on ambient air quality, and evaluates health impacts in economic terms. Various policy, economic and technical options can then be evaluated for their cost-effectiveness. An optimization model is also built-into the spreadsheet to determine the best combination of options that can meet desired objectives (e.g. minimum cost) subject to constraints (e.g. ambient quality standards).

System requirements for SIM-AIR

The following hardware and software is required to run SIM-AIR:

- An Intel Pentium 133 or equivalent processor running Windows 95, 98, NT version 4.0 or later, 2000 XP; 16 MB RAM (Windows 95 or 98; 24 MB recommended) or 24 MB of RAM (Windows NT; 32 MB recommended) plus 20 MB of available disk space; a color monitor
- Microsoft® Excel (versions above 2000)

Installing SIM-AIR

SIM-AIR is a simple spreadsheet program which can be opened using Microsoft Excel. Copy SIM-AIR.XLS to your computer and launch it. Ensure that you enable 'macros' while opening the file. Simply click on 'Enable macros' when the Excel program asks for it. To use the optimization function, ensure that you have the Solver tool launched. To enable the Solver, go to Tools, click on Add-Ins and check on Solver.

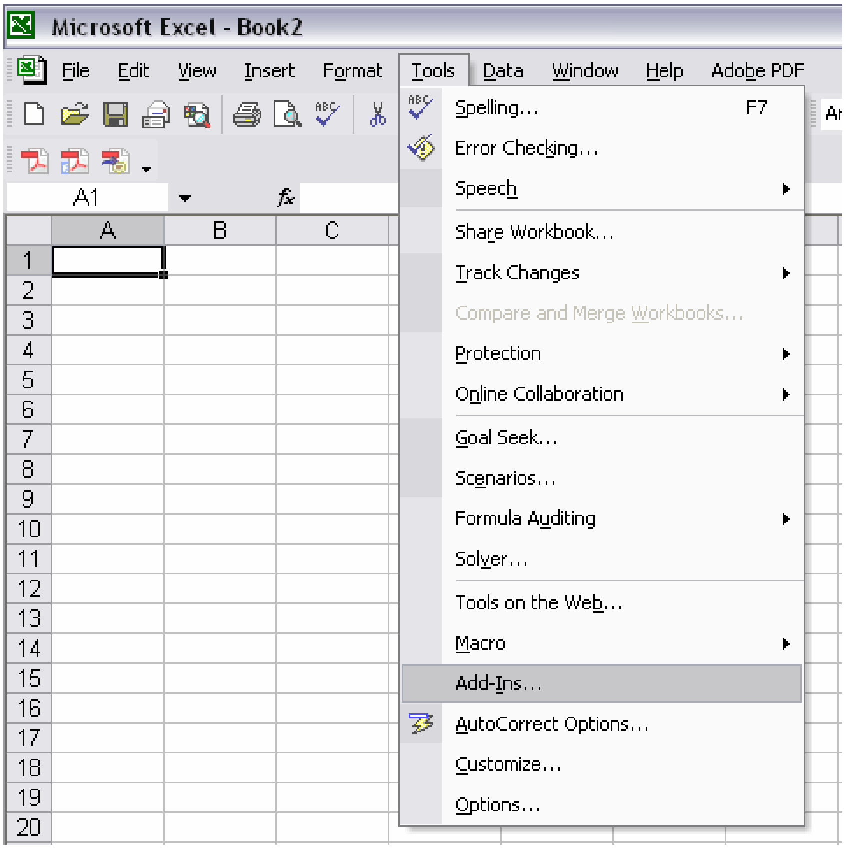


Figure 1.1 How to select Add-Ins option in Microsoft® Excel

Note: It should be noted that this spreadsheet is only a prototype to start developing such decision support system tools and should not be used to make decisions in the form presented. Depending on the user requirements, these should be adapted for the local decision making objectives, parameters, data and context. This is second improvised version of the spreadsheet. Other versions will be uploaded as we keep on improving on the present version. Users are also requested to give us a feedback on how the present version could be improved.

CHAPTER 1

1.1 Model overview

The spreadsheet is based upon as simple model which connects emissions, ambient air quality and health. The aim is to provide a simple, interactive system to analyze the environmental, economic (and eventually social) impacts of various management options. The models used in SIM-AIR are simple and open for modification or improvements. SIM-AIR can help by visualizing a "first cut" rapid assessment of options with available data and determine critical areas for future work.

1.2 Why an integrated model?

Urban air quality has become a significant issue in all metropolitan cities. Air quality is important for health as well as the economy. Most of the cities of developing nations are facing from deteriorating air quality and problems associated with air pollution. In spite of the alarming fact, the information available is highly disorganized, poor and often inaccessible. There are several challenges faced by management on account of scattered data and lack of institutional networking and information sharing. Also there is lack of access to tools like SIM-AIR for interested stakeholders to examine options. In light of these challenges, a need for integrated decision support tool has been identified.

Today, most of the models require large amount of data and prior expertise. They are also not very flexible and are usually location specific.

SIM-AIR's integrated approach consists of the following:

- allow definition of all major types of urban emission sources. E.g. point, line, area
- provide default emission factors where available (user can change these factors based on local context)
- interface emission computation model with key technology and management option (e.g. fuel change, conversion of two stroke to four stroke engines etc.)
- link emissions to ambient air quality through an externally created or supplied source-receptor matrix (this allows user to apply an urban air quality model of his/her choice. SIM-AIR is thus independent of the air quality model)
- allows estimation of economic impacts on health. User can edit exposure-damage relationships according to local knowledge
- allow plugging of cost data for a broad range of Air Quality Management (AQM) options
- encourage rapid assessment of management option in terms of cost effectiveness
- provide an optimization scheme to identify most cost-effective combination of options

1.3 Structure of SIM-AIR

SIM-AIR has a 'Main' worksheet and eight other worksheets that show results of various calculations and data according to 'themes'. These themes, excluding 'Main', are as follows:

- Emission Distribution
- Vehicle Data
- Emissions
- Transfer matrix
- Concentrations
- Impacts
- Options
- Help

The 'Main' worksheet contains the model interface and eight different 'Management Options' as decision variables.

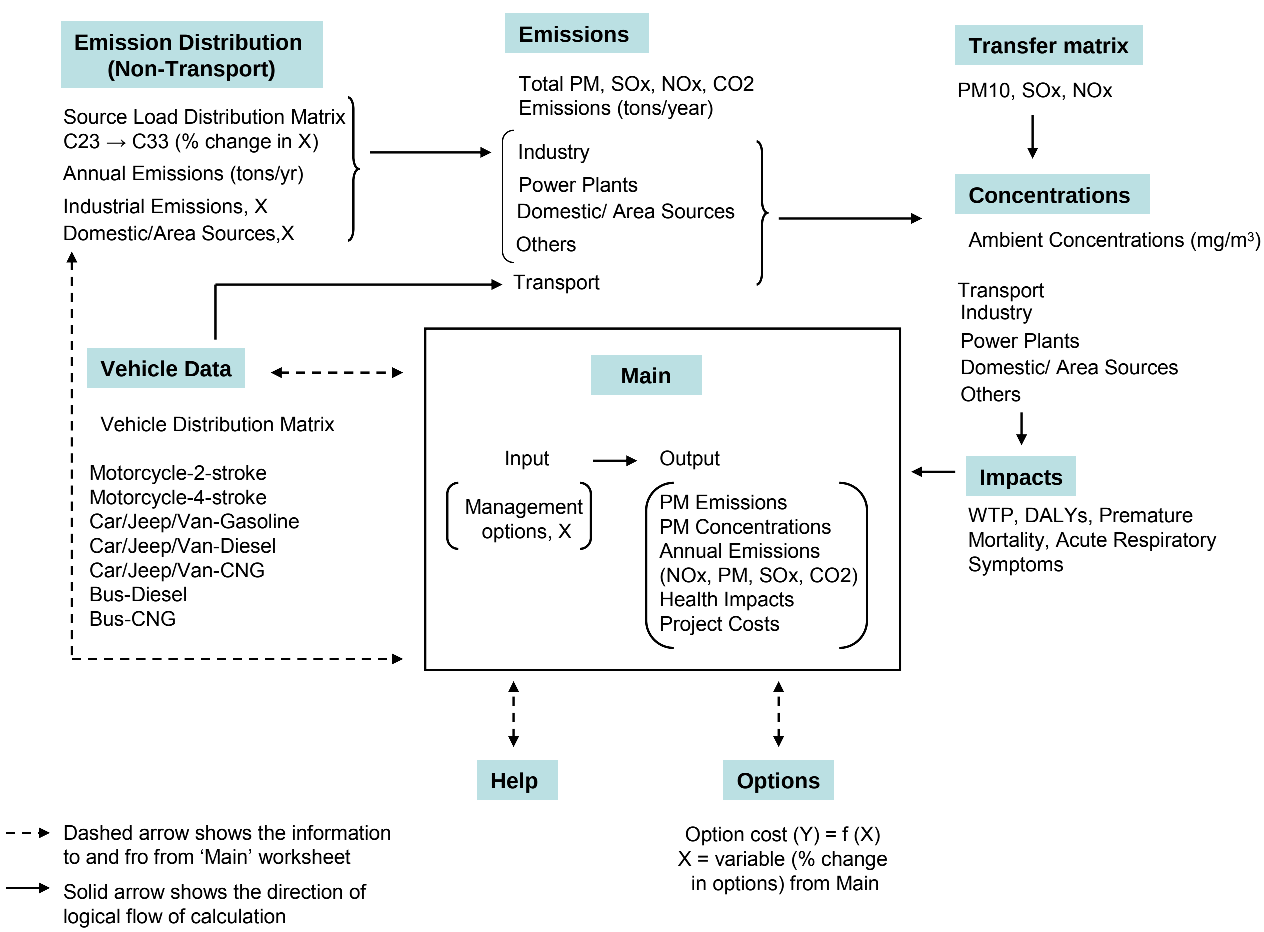


Figure 1.1 Structure of SIM-AIR

The percentage change in adoption of the themes is the basis of calculations throughout the spreadsheets. For e.g., if 10 percent of total fleet of diesel buses is to be converted to CNG, the decision variable, X, is10%.

1.4 Model inputs

The input data contains following information for any grid, C_{ij}:

1. Emission distribution
2. Ambient concentration
3. Health impacts
4. Management options

The following chapters explain in detail the different sections of the spreadsheet. Various calculations involved and the linkages between different parts of the model are explained in these chapters. The last chapter on management section includes a special section on how to incorporate new management options in the existing spreadsheet. It gives the reader a step-by-step procedural guidance to include different management options and change the existing cost equations.

CHAPTER 2

2.1 Emission Distribution

The emission inventory is the prime requirement in AQM tool. The worksheet titled as "Emission Distribution" contains the emission distribution pattern for the city. This is one of the inputs required for SIM-AIR. The user provides data on emission distribution. As a base-case, model data has already been supplemented in the spreadsheet. This section consists of a source load distribution matrix, vehicular characteristics, vehicular emission distribution and finally calculates emissions in terms of PM_{10}, SO_x and CO_2. The emission sources can be listed as follows:

- Transport
- Industrial emissions
- Power plants
- Domestic/area sources
- Others

The city for which air quality planning is to be done is divided into grids, C_{ij}. Generally, 1×1 km grid size is recommended. Each grid is then analyzed for emissions.

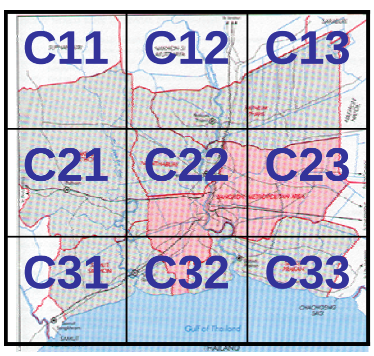


Figure 2.1 Division of city into grids

2.2 Emission load matrix

An emission load distribution matrix for the following parameters is provided as input:

- Industrial emissions
- Power plants
- Domestic/area sources
- Others

All emissions are computed on annual basis in tons/year.

Source	C11	C12	C13	C21	C22	C23	C31	C32	C33	Total
Industrial Emissions	1%	1%	1%	5%	20%	50%	5%	10%	7%	100%
Power Plants	0%	0%	0%	0%	0%	75%	0%	25%	0%	100%
Domestic/Area Sources	2%	2%	2%	3%	30%	30%	1%	25%	5%	100%
Others	10%	10%	10%	15%	30%	10%	5%	5%	5%	100%

Table 2.1 Source load matrix

The matrix in Table 2.1 contains the distribution of emission sources in each grid. The emission sources are categorized into different categories such as industrial emissions, emissions from power plants etc.

$$C_{23} = 50\,\% \times (1-\Delta I) \qquad 2.1$$

$$C_{33} = 7\,\% + 50\,\% \times \Delta I \qquad 2.2$$

where, ΔI = percentage shift of industries from grid C_{23} to grid C_{33}.

SIM-AIR has such equations to allow evaluation of management options of shifting industries.

The emission load matrix is completely city specific. In the above equations, the distribution of industrial emission of 50% in grid C_{23} and 7% in grid C_{33} can be different for another city.

2.3 Computation of total emissions

Except emissions from transport sector, for the rest of the sources following formula is used:

$$E = AL * EF * (1 - CE) \qquad 2.3$$

where, E = emissions,
AL = activity level
EF = emission factor
CE = control efficiency

Total emissions are the sum of annual emissions in tons/year for the following sources:

2.3.1 Industrial emissions:

$$PM_{10} = 7500 \times [1-(E_P \times \Delta E \times 100)] \qquad 2.4$$

$$SO_x = 250000 \times [1-(E_S \times \Delta E \times 100)] \qquad 2.5$$

$$CO_2 = 800000 \times [1-(E_C \times \Delta E \times 100)] \qquad 2.6$$

where, ΔE = percentage change in energy efficiency of industries,
E_P, E_S, E_C are elasticity of emissions for energy efficiency for PM_{10}, SO_x, CO_2 respectively.

ΔE is one of the decision variables and total industrial emissions can be controlled by changing ΔE.

E_P	E_S	E_C
0.50%	0.50%	0.40%

Table 2.2 Elasticity factors (% reduction in emissions per % conversion)

2.3.2 Power plants:

These emissions are to be entered directly. There are no management options linked to power plants.

2.3.2 Domestic/area sources:

$$PM_{10} = 1000 \times [1-(E'_P \times \Delta F \times 100)] \quad 2.7$$
$$SO_x = 1500 \times [1-(E'_S \times \Delta F \times 100)] \quad 2.8$$
$$CO_2 = 200000 \times [1-(E'_C \times \Delta F \times 100)] \quad 2.9$$

where,
ΔF = percentage change in fuel usage, i.e., from coal to LPG
E'_P, E'_S, E'_C are elasticity of emissions for coal to LPG conversion for PM_{10}, SO_x, CO_2 respectively

ΔF is again one of the decision variables where change in fuel usage can lead to significant changes in emissions.

E'_P	E'_S	E'_C
0.50%	0.50%	0.40%

Table 2.3 Elasticity factors (% reduction in emissions per % conversion)

2.3.3 Others:

These sources include other miscellaneous sources of emissions for PM_{10}.

Following is a result of total annual emissions when none of the management options are introduced.

Total Emissions	**Annual Emissions (tons/yr)**		
	PM_{10}	**SO_x**	**CO_2**
Industrial Emissions	7,500 +	250,000	800,000
Power Plants	2,000	150,000	100,000
Domestic/Area Sources	1,000	1,500	200,000
Others	1,000	-	-

Table 2.4 Total emissions for base case

2.3.4 Emissions from transport sector:

The emissions from transport sector require different calculations and inputs. From various data sources, such as Regional Transport Office (RTO), a spatial distribution of vehicles is required. This distribution needs to be in the form of matrix that includes vehicle type, total number of vehicles of each type Following is a snapshot of such a matrix for the example base case:

Vehicle Type	**Number of Vehicles**	**Spatial Distribution Factor**									
		C11	C12	C13	C21	C22	C23	C31	C32	C33	Total
Motorcycle-2-stroke	500,000	2%	2%	2%	3%	30%	30%	3%	25%	3%	100%
Motorcycle-4-stroke	600,000	2%	2%	2%	3%	30%	30%	3%	25%	3%	100%
Car/Jeep/Van-Gasoline	1,000,000	2%	2%	2%	3%	30%	30%	3%	25%	3%	100%
Car/Jeep/Van-Diesel	450,000	2%	2%	2%	3%	30%	30%	3%	25%	3%	100%
Car/Jeep/Van-CNG	20,000	2%	2%	2%	3%	30%	30%	3%	25%	3%	100%
Taxi-Gasoline	50,000	2%	2%	2%	3%	30%	30%	3%	25%	3%	100%
Taxi-Diesel	3,000	2%	2%	2%	3%	30%	30%	3%	25%	3%	100%
Taxi-CNG	100	2%	2%	2%	3%	30%	30%	3%	25%	3%	100%
Bus-Diesel	150,000	2%	2%	2%	3%	30%	30%	3%	25%	3%	100%
Bus-CNG	-	2%	2%	2%	3%	30%	30%	3%	25%	3%	100%
Truck-Diesel	80,000	2%	25%	2%	2%	25%	9%	25%	5%	5%	100%
Heavy Duty-Diesel	7,500	5%	5%	4%	3%	5%	30%	3%	15%	30%	100%
Total	**2,860,600**										

Table 2.5 Snapshot of vehicular distribution

Total emissions for a type of vehicle can be computed by:

$$E = VKT \times E \times N \times 365 \qquad 2.10$$

where, VKT = vehicle travel per day
E = emission factor
N = number of vehicles

Sample calculation

PM_{10} for Motorcycle-2-stroke = 30 * 0.23 * 500000 * 365 / 1000000
= 1259 tons/yr

In the above sample calculation, the factor of 365 is introduced because VKT is on a daily basis and the annual emissions are on yearly basis. The division by 1000000 is the factor to convert gm emissions into tons. Following matrix shows annual emissions of vehicles for the base example case:

Vehicle Characteristics		**Emission Factors (gm/km)**			**Total Emissions (tons/yr)**		
Vehicle Type	**VKT (km/day)**	**PM_{10}**	**SO_x**	**CO_2**	**PM_{10}**	**SO_x**	**CO_2**
Motorcycle-2-stroke	30	0.23	0.14	70	1,259	767	383,250
Motorcycle-4-stroke	30	0.04	0.04	50	263	263	328,500
Car/Jeep/Van-Gasoline	60	0.40	0.20	400	8,760	4,380	8,760,000
Car/Jeep/Van-Diesel	60	0.95	0.60	600	9,362	5,913	5,913,000
Car/Jeep/Van-CNG	60	0.20	0.10	200	88	44	87,600
Taxi-Gasoline	100	0.35	0.60	400	639	1,095	730,000
Taxi-Diesel	100	0.90	0.50	600	99	55	65,700
Taxi-CNG	100	0.10	0.10	200	0	0	730
Bus-Diesel	130	2.50	1.50	1,200	17,794	10,676	8,541,000
Bus-CNG	130	0.70	0.50	600	-	-	-
Truck-Diesel	50	3.50	2.20	1,200	5,110	3,212	1,752,000
Heavy Duty-Diesel	300	1.00	0.60	1,200	821	493	985,500
				Total	**44,195**	**26,897**	**27,547,280**

Table 2.6 Computation of vehicular emission for base case.

Now that most types of emissions sources are calculated, these need to be summed up for arriving at final annual emissions of particulate matter, sulfur dioxide emissions and carbon dioxide. The annual emissions are calculated as follows:

Source	**Computation**
Transport	C_{ij} = total PM_{10} emissions for respective vehicles, (Table 2.6) × $\sum C_{ij}$ (spatial distribution of vehicles, Table 2.5)
Industry	C_{ij} = total PM_{10} emission from industries (from Table 2.4) × C_{ij} (% of emission by industries in respective grid, from Table 2.1)
Power Plants	C_{ij} = total PM_{10} emissions from power plants (from Table 2.4) × C_{ij} (% of emission by power plants in respective grid, from Table 2.1)
Domestic area	C_{ij} = total PM_{10} emissions from domestic area (from Table 2.4) × C_{ij} (% of emissions by domestic sources in respective grid, from Table 2.1)
Others	C_{ij} = total PM_{10} emissions from other sources (from Table 2.4) × C_{ij} (% of emissions by other sources in respective grid, from Table 2.1)

Sample calculation

Total PM_{10} (industry) in C_{11} = 7500 (PM_{10} industries, Table 2.4) × 1/100 (where % of emission by industries in C_{11} is 1% , from Table 2.1)

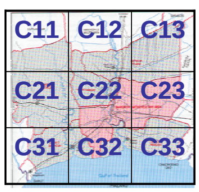
= 75

Following is a summary of annual PM_{10} emissions for example base case:

Source	**Total**	**C11**	**C12**	**C13**	**C21**	**C22**	**C23**	**C31**	**C32**	**C33**
Transport	44,195	909	2,084	900	1,275	12,798	12,185	2,450	9,945	1,650
Industry	7,500	75	75	75	375	1,500	3,750	375	750	525
Power Plants	2,000	-	-	-	-	-	1,500	-	500	-
Domestic/ Area Sources	1,000	20	20	20	30	300	300	10	250	50
Others	1,000	100	100	100	150	300	100	50	50	50
Total	*55,695*	*1,104*	*2,279*	*1,095*	*1,830*	*14,898*	*17,835*	*2,885*	*11,495*	*2,275*

Table 2.7 Summary of total annual PM_{10} emissions for base case.

This session then ends with calculation of total annual emissions with respect to particulate matter, SO_X and CO_2. Figure 2.2 shows these emissions in the format of grid



1,104	**2,279**	**1,095**
1,830	**14,898**	**17,835**
2,885	**11,495**	**2,275**

Figure 2.2 Annual emissions of example base case in grid format.

It may be observed that grids C_{22}, C_{23} and C_{32} dominate the overall particulate emissions in the city.

CHAPTER 3

3.1 Ambient Concentration

A typical air pollution model for a single source can be defined as the product of total emissions and transfer coefficients:

$$C = m\,Q \qquad 3.1$$

where, C = ambient air concentration,
m = constant,
Q = total emissions

In equation 3.1, *m* is the transfer coefficient and depends on source, atmospheric stability and the diffusion field. The transfer coefficient plays in important role in calculation of ambient air concentration provided emission loads are given and vise versa. The biggest issue here is how to obtain the transfer coefficients.

3.2 Transfer Coefficients

The transfer coefficient indicates the incremental change in concentration in any cell for a unit change in emissions in any one cell. It defines the relationship between source and receptor.

Mathematically, the source-receptor relationship m_{ij} is defined as

$$m_{ij} = \partial c_j / \partial q_i \qquad 3.2$$

where, q = source occupying a certain three-dimensional space and time interval (dimension being kg)
c = receptor (dimension being kg/m^3)

Figure 3.1 describes the schema of computing concentrations using emissions

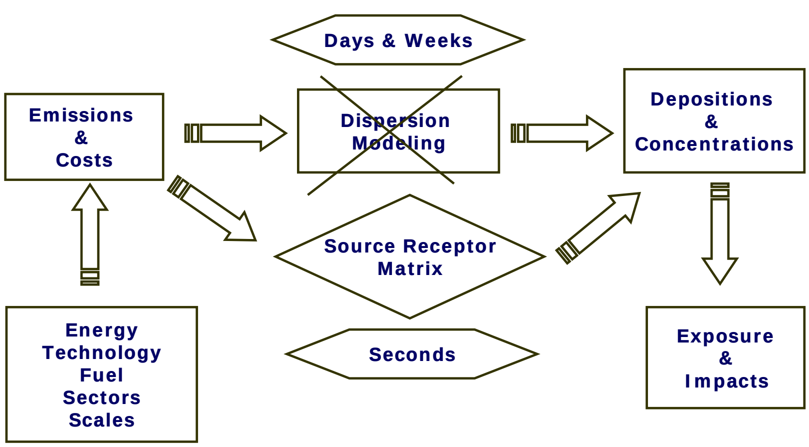


Figure 3.1 Computation of concentrations using emissions

In a linear source-receptor relationship, m_{ij} is a constant and $\partial c_j/\partial q_i$ can be replaced by c_j/q_i. Hence a source-receptor matrix (SRM), M is generated with elements m_{ij}. SRM can be generated using box model, puff model, plume model, Eulerian or Lagrangian models. A grid-based simulation model is run with a base case and concentrations in each cells are checked. The minimum requirement of the model is that it should be area based model. Then the emissions are increased in one cell (say C_{11}) by one unit, and changes in the concentrations in the rest of the cells are noted. The difference in concentrations would yield one row of the transfer matrix. This process when repeated and results summed up on a cumulative basis for all the grids, results in a transfer matrix. The important factor that governs the generation of transfer matrix is the meteorological data (such as wind speed, class, direction etc.).

The transfer matrix provided in SIM-AIR is based on following assumptions:

3 Wind is blowing from south-west to north-east
4 Maximum impact is for the same cell
5 Next in line is the neighboring cell in same direction as wind

Following is the transfer matrix for PM_{10}-Area:

		Target Cell								
		C11	**C12**	**C13**	**C21**	**C22**	**C23**	**C31**	**C32**	**C33**
Source Cell	**C11**	.0033	.0008	.0008	.0008	.0008	.0008	.0008	.0008	.0008
	C12	.0008	.0033	.0008	.0008	.0008	.0008	.0008	.0008	.0008
	C13	.0008	.0008	.0033	.0008	.0008	.0008	.0008	.0008	.0008
	C21	.0008	.0021	.0008	.0033	.0008	.0008	.0008	.0008	.0008
	C22	.0008	.0008	.0021	.0008	.0033	.0008	.0008	.0008	.0008
	C23	.0008	.0008	.0017	.0008	.0008	.0033	.0008	.0008	.0008
	C31	.0008	.0008	.0013	.0008	.0021	.0008	.0033	.0008	.0008
	C32	.0008	.0008	.0013	.0008	.0008	.0021	.0008	.0033	.0008
	C33	.0001	.0001	.0001	.0001	.0001	.0001	.0001	.0001	.0033

Table 3.1 Transfer matrix for PM_{10}-Area (primary)

It may be observed that the effect of increase in concentration of PM emission in a cell, say C_{11} would be maximum on C_{11} and minimum on the cell farthest from it, i.e., C_{33}. Each cell will behave in a different way since the activities and meteorological conditions of each cell are different. The present transfer matrix is based on some hypothetical city. For real time situations, the actual data will be required based on city's activities.

Transfer matrices for SOx and NOx can be generated in the similar manner. Sample transfer coefficients for example base case have been provided in the spreadsheet. The terms, 'primary' and 'secondary' PM are used under this theme.

- *Primary particles* are released directly into air and tend to be found closer to their source. For e.g. dust, windblown soil etc.

- *Secondary particles* are formed by the chemical reaction of gases in the air; these tend to be spread more evenly in rural and urban areas. For e.g. NOx, SOx etc.

PM primary = Total annual PM_{10} emissions (Table 2.7) × Transfer coefficients matrix for PM_{10} primary (Table 3.1)

Hence the PM primary matrix which is a product of matrix multiplication of total PM_{10} emissions matrix and transfer coefficients matrix is as follows:

PM10-Primary	**C11**	**C12**	**C13**	**C21**	**C22**	**C23**	**C31**	**C32**	**C33**
Transport	37.9	42.4	69.2	38.8	70.7	78.5	41.7	60.5	41.0
Industrial Emissions	6.1	6.5	11.5	6.8	10.1	16.2	6.8	7.7	7.6
Power Plants	1.7	1.7	3.1	1.7	1.7	6.0	1.7	2.9	1.7
Domestic/Area Sources	0.8	0.9	1.6	0.9	1.6	1.9	0.8	1.4	1.0
Others	1.0	1.2	1.5	1.2	1.6	1.1	0.9	0.9	1.0
Total	47.5	52.7	87.0	49.3	85.6	103.7	52.0	73.5	52.1

Table 3.2 Ambient concentration for PM_{10} primary

Similarly, PM secondary = Total annual PM_{10} emissions (Table 2.7) × Transfer coefficients matrix for PM_{10} secondary (SOx and NOx)

The total PM concentration will be the sum of corresponding elements of above matrices, i.e.,

PM total = PM primary + PM secondary

Hence the total PM ambient concentration matrix will be as follows:

PM10-Total	**C11**	**C12**	**C13**	**C21**	**C22**	**C23**	**C31**	**C32**	**C33**
Transport	39.3	44.0	71.7	40.2	73.3	81.4	43.3	62.7	42.4
Industrial Emissions	14.6	15.7	27.7	16.4	24.3	38.9	16.4	18.6	18.2
Power Plants	7.4	7.4	13.9	7.4	7.4	26.9	7.4	13.0	7.4
Domestic/Area Sources	0.7	1.0	1.3	0.8	1.3	1.5	0.7	1.2	0.8
Others	1.0	1.2	1.5	1.2	1.6	1.1	0.9	0.9	1.0
Total	**63.1**	**69.3**	**116.2**	**66.0**	**107.8**	**149.8**	**68.7**	**96.4**	**69.8**

Table 3.5 Total ambient concentration

It may be observed that ambient concentrations in grids C_{13}, C_{22} and C_{23} are highest and therefore call for appropriate strategy to curb down the concentration.

Since the aim of the spreadsheet is to come up with different management options to improve air quality, ambient air quality standards will need to be defined for each cell. The difference between ambient air quality standards and simulated/estimated values will be used to calculate the health effects. For e.g., if the standard for cell C_{11} is set to 50 and estimated emission is 63.1, then the health impact will be calculated on the basis of the difference between the observed value and the standard. It should be noted that only if the observed value is more than the standard, it will be used to calculate the health impact.

Following table gives the difference between the standards and observed values for example base case:

PM10-Total	C11	C12	C13	C21	C22	C23	C31	C32	C33
Total	63.1	69.3	116.2	66.0	107.8	149.8	68.7	96.4	69.8
Reference	**50**	**50**	**50**	**50**	**50**	**50**	**50**	**50**	**50**
Exceedances	**13.1**	**19.3**	**66.2**	**16.0**	**57.8**	**99.8**	**18.7**	**46.4**	**19.8**

Table 3.6 Difference between standard and estimated particulate emissions.

It may be observed that almost all grids exceed the ambient air quality standard. The most critical grids, however, are grids C_{13}, C_{22} and C_{23}. The management options could be chosen in a way to minimize ambient air concentrations in these grids.

CHAPTER 4

4.1 Health Impacts

Health impacts are one of the important parameters while dealing with air quality planning. There are various parameters to assess the health impacts. Following are some of the parameters that can be used to assess health impacts:

- Premature Mortality
- Adult Chronic Bronchitis
- Respiratory Hospital Admission
- Cardiac Hospital Admission
- Emergency Room Visit
- Child Acute Bronchitis
- Asthma Symptom Day
- Restricted Activity Day
- Acute Respiratory Symptom Day

It is still a debatable issue as to how to evaluate health impacts. SIM-AIR takes into consideration the above parameters and other factors such as Daily Adjusted Life Years (DALYs) for health impact calculations. DALYs combine the impacts of premature mortality and disability associated with various health conditions. One DALY equates to one year of healthy life lost.

WTP or willingness-to-pay approach is an evaluation method used to determine the maximum amount of money an individual is willing to pay to gain a particular benefit (e.g. receive a healthcare service). The method is often used in cost-benefit analysis to quantify a benefit in monetary terms[1].

In the previous section, the ambient concentration and the difference in air quality standards and estimated values were calculated. Health impact is product of change in ambient concentration and the effect/capita/change in concentration. The data below is again dependent on number of factors and table presented below shows values of a particular case. These values will change from city to city as well as from one country to the other.

Health Effect	**Effect/Capita/Dmg/m^3**	**DALY/10,000 cases**	**WTP-Monetary Value per case (1999 US $)**
Premature Mortality	0.000014	100,000	1,620,000
Adult Chronic Bronchitis	0.00004026	12,037	195,000
Respiratory Hospital Admission	0.0000057	264	4,225
Cardiac Hospital Admission	0.000005	20,000	300,000

[1] Kielhorn & von der Schulenburg 2000, http://www.euro.who.int/observatory/Glossary/TopPage?phrase=W

Emergency Room Visit	0.00024	3	126
Child Acute Bronchitis	0.000544	12,037	195,000
Asthma Symptom Day	0.0029	4	63
Restricted Activity Day	0.03828	3	53
Acute Respiratory Symptom Day	0.30172	3	44

Table 4.1 Examples of health related parameters used in the base case.

The matrix multiplication of change in ambient concentration data for different cells with effect/capita/change in ambient concentration will give the effect/capita. The results are summarized below:

4.2 Effect/capita

The respective health effect parameters are the result of matrix multiplication of effect/capita matrix with population matrix. Population matrix is the grid vice distribution of population.

Health Effect	**C11**	**C12**	**C13**	**C21**	**C22**	**C23**	**C31**	**C32**	**C33**	**Total**
Premature Mortality	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**
Adult Chronic Bronchitis	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.01**
Respiratory Hospital Admission	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**
Cardiac Hospital Admission	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	**0.00**
Emergency Room Visit	0.00	0.00	0.01	0.00	0.01	0.02	0.00	0.01	0.00	**0.07**
Child Acute Bronchitis	0.00	0.01	0.03	0.01	0.03	0.05	0.01	0.02	0.01	**0.16**
Asthma Symptom Day	0.02	0.04	0.16	0.03	0.15	0.25	0.04	0.11	0.04	**0.85**
Restricted Activity Day	0.31	0.53	2.18	0.41	1.95	3.25	0.51	1.49	0.54	**11.17**
Acute Respiratory Symptom Day	2.44	4.18	17.16	3.22	15.34	25.65	4.03	11.76	4.29	**88.06**

Table 4.2 Health effect/capita

Hence the multiplication of population with effect/capita will give the overall effect. Population matrix is as follows:

200,000	300,000	1,000,000
200,000	3,000,000	4,000,000
200,000	1,000,000	100,000

Table 4.3 The population distribution matrix

This data is just for a hypothetical city considered in the model. The overall effect which is given by matrix multiplication of effect/capita matrix with population matrix and can be summarized as:

Health Effect	Effect on total population
Premature Mortality	8,406
Adult Chronic Bronchitis	24,173
Respiratory Hospital Admission	3,422
Cardiac Hospital Admission	3,002
Emergency Room Visit	144,104
Child Acute Bronchitis	326,635
Asthma Symptom Day	1,741,253
Restricted Activity Day	22,984,546
Acute Respiratory Symptom Day	181,162,413

Table 4.4 Overall Effect

4.3 Total Health Effects

Above calculation were on the per case basis. Hence final value will be multiplication of value per case times the population. The values could be summarized as:

Health Effect	DALYs	WTP (1999_Billion_US_$)	Effect	C11	C12	C13	C21	C22	C23	C31	C32	C33
Premature Mortality	84,061	13.62	8406	23	58	796	30	2,135	4,761	37	546	20
Adult Chronic Bronchitis	29,098	4.71	24,173	65	167	2,290	86	6,139	13,692	107	1,570	57
Respiratory Hospital Admission	90	0.01	3,422	9	24	324	12	869	1,939	15	222	8
Cardiac Hospital Admission	6,004	0.90	3,002	8	21	284	11	762	1,700	13	195	7
Emergency Room Visit	43	0.02	144,104	387	997	13,652	511	36,595	81,623	641	9,357	341
Child Acute Bronchitis	393,171	63.69	326,635	878	2,261	30,944	1,159	82,948	185,011	1,452	21,209	773
Asthma Symptom Day	697	0.11	1,741,253	4,682	12,052	164,957	6,180	442,188	986,273	7,741	113,061	4,119
Restricted Activity Day	6,895	1.22	22,984,546	61,802	159,084	2,177,433	81,580	5,836,884	13,018,801	102,185	1,492,410	54,367
Acute Respiratory Symptom Day	54,349	7.97	181,162,413	487,117	1,253,888	17,162,358	643,004	46,005,869	102,613,185	805,414	11,763,061	428,516

Table 4.5 Final health effects

It may be observed that dominating health effect is respiratory disease which is the result of large particulate emissions in the example base case. Hence management option could be chosen accordingly to minimize the health effect.

CHAPTER 5

5.1 Introduction

The objective of SIM-AIR is to assess various management options for connecting air emissions to meet required ambient air quality standards. This section explains these management options. Each management option has a cost implication and benefit in terms of improved ambient air quality.

In order to arrive at the best combination of different management options, the spreadsheet uses an optimizer. Guidance is provided in this chapter to show how to incorporate new management options.

5.2 Management Option

Planners and decision makers are often crippled by the lack of information on direct implications of certain policy measure or a management option. Either the implications are often neglected or difficult to assess. The spreadsheet helps in identifying the missing correlation between policy measures and its implication using simple mathematical and financial tools. It lists various management options which aim at improving air quality. All the management options are linked to cost and health impacts based on percentage change in the considered option. Cost and health implications can be viewed on the Main worksheet by varying the scrollbar provided in front of each management option.

The management options programmed in SIM-AIR are as follows:

1. CNG Conversion of Buses (% of bus fleet converted to CNG as alternate fuel)
2. Low-Sulfur Diesel (% reduction of sulfur levels in diesel)
3. Energy Efficiency in Industry
4. Shift Industries from grid C_{23} to C_{33}
5. Coal to LPG shift in Domestic/Area sources
6. Scrappage (retirement of motorcycles with 2-stroke engines and promotion of using motorcycles with 4-stroke engines)
7. Trucks using Bypass (through grid C_{21} and not through grid C_{22})
8. Encourage Public Transport (% cars off road)

Each of the management options are described below:

5.2.1 CNG Conversion of Buses: This is one of the possible options to reduce PM emissions. Here, the decision variable is percentage of bus fleet converted to CNG. The impact would be reduced particulate emissions as buses change from diesel to CNG as cleaner fuel.

If X is the total percentage of buses converted to CNG, then total bus population would be given by:

Bus population = Total diesel buses × (1-X) + Total diesel buses × (X)

It should be noted that diesel buses will emit different amount of PM and SOx emissions as compared to buses converted to CNG. This will change the annual emissions and therefore will change the annual emission loads. Consequently, the extent of health impacts will change.

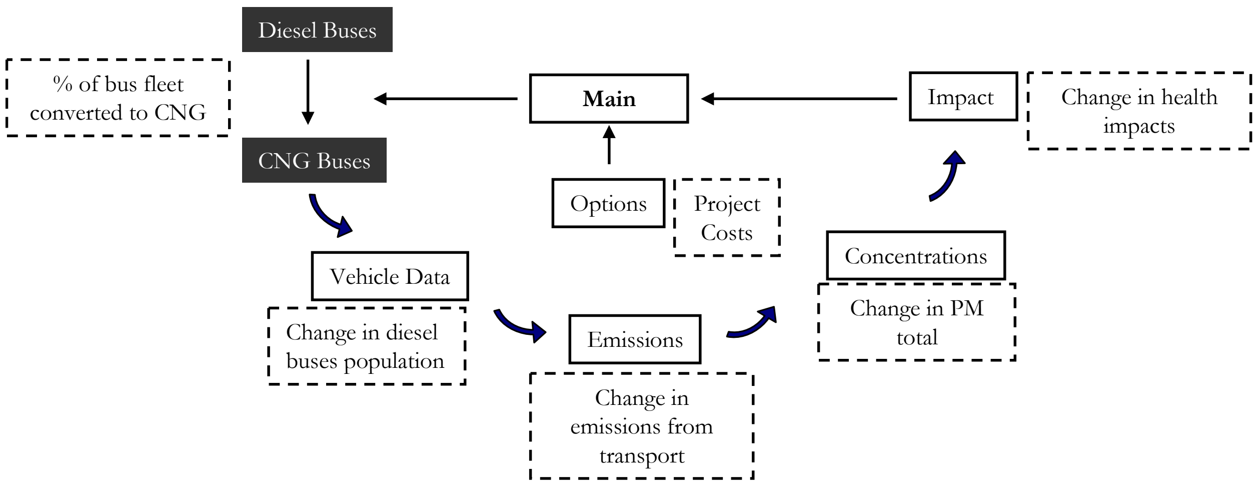


Figure 5.1 Changes in the spreadsheet on implementing the management option, "Conversion of bus fleet from diesel to CNG"[2]

Implementation of this option would require investments on items such as:

- CNG kits
- CNG filling stations
- CNG Transport

The additional areas which would require investment are:

- CNG supply infrastructure
- Special maintenance of the converted fleet

A similar management option was implemented in the city of New Delhi, India. A typical cost curve based on New-Delhi experience is as follows:

[2] Boxes with solid outlines represent different worksheets as they appear in the spreadsheet, boxes with dashed outline represent the change involved and boxes in gray color represent the management option

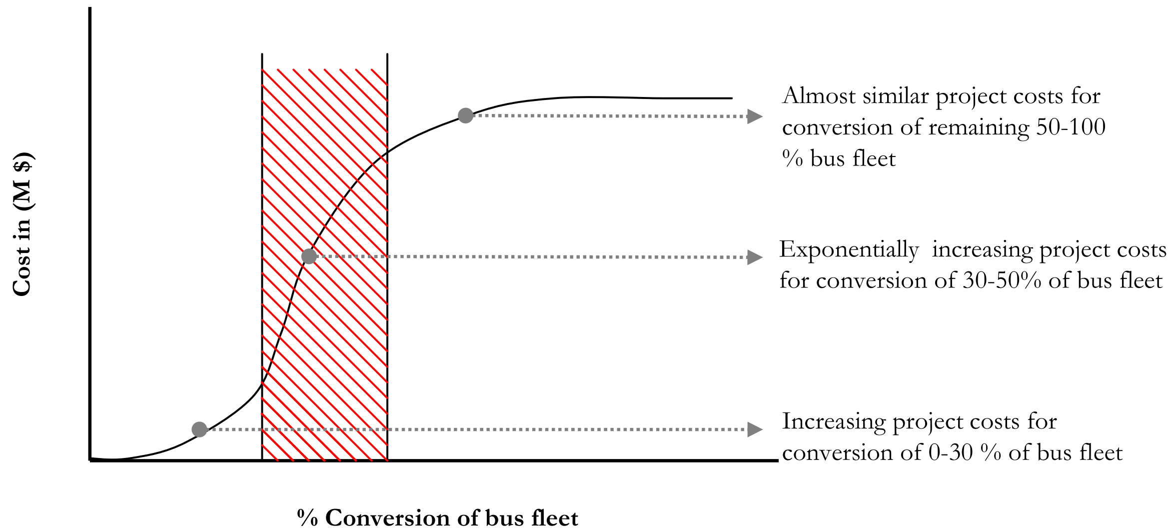


Figure 5.2 Cost curve for the management option, "Conversion of bus fleet from diesel to CNG"

The costs can be modeled as quadratic function as follows:

$$\text{Cost (M \$)} = B \times X + C \times X^2$$

where X is the percentage conversion of bus fleet from diesel to CNG as cleaner fuel. For the New Delhi data, B and C work out to be 13.5 and 0.06 respectively.

If the cost curve is observed carefully, one would find that the policy makers or managers need to be extremely careful about the conversion of fleet since the conversion costs rise significantly when the 30-50 % of diesel bus fleet is converted to CNG. Hence a proper strategy should be envisaged for phase-wise conversion of the fleet so as to minimize the costs.

5.2.2 Low-Sulfur Diesel: This management option considers reducing sulfur levels in diesel. Introducing this option would result in fewer secondary particulates in emissions. Change in emission factor of SOx of diesel vehicles would necessarily lead to change in emission levels as shown in figure 5.3:

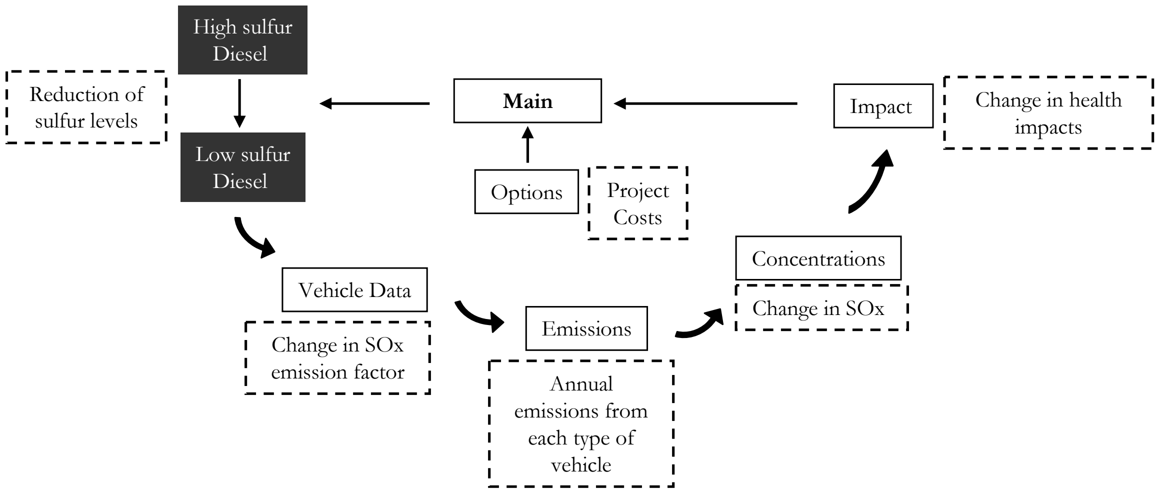


Figure 5.3 Changes in the spreadsheet on implementing the management option, "Low-sulfur diesel"

Reducing the sulfur level is cost-intensive project. At present it takes some amount of capital (which is the capital required for processing crude oil to get diesel) to obtain diesel laded with 2000 ppm sulfur. The cost required at the process side to reduce sulfur to 500 ppm would require huge amount of investments. It should be noted that to reduce sulfur level below 500 ppm, the investments are even higher. By comparing processing costs, following curve is obtained:

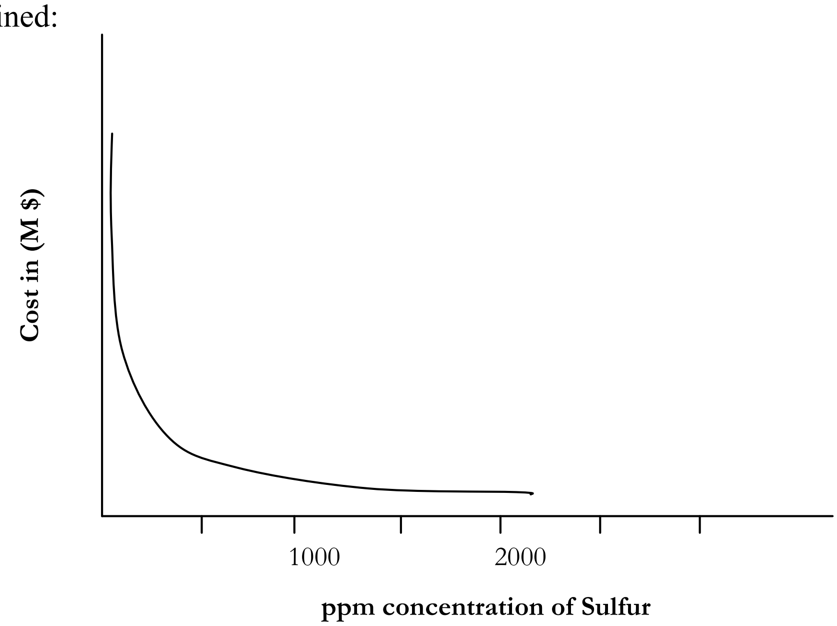


Figure 5.4 Cost curve for the management option, "Low-sulfur diesel"

The costs can be modeled as exponential function as follows:

$$\text{Cost (M \$)} = A+B\times X^C$$

where X is the percentage reduction of sulfur levels. On Comparing processing costs against the cost curve, A, B and C came out to be -8.75, 40281 and -1.11 respectively.

Having obtained the cost curves and cost coefficients, these coefficients are appropriately linked in the spreadsheet.

5.2.3 Energy Efficiency in Industry: Energy efficiency in industries is one of the factors that play important role in emissions. Improving efficiency in industries not only saves the costs paid to protect environment but also provides promising returns to the industry in terms of increased profits and lower resource consumption. Improving energy efficiency also means lesser amount of fuels burnt leading to lesser emissions. Elasticity of emissions for energy efficiency is the ratio of percentage reduction in emissions to percentage conversion. This ratio is fixed for all types of emissions. Following figure summarizes the flow of logic and calculations for the considered management option:

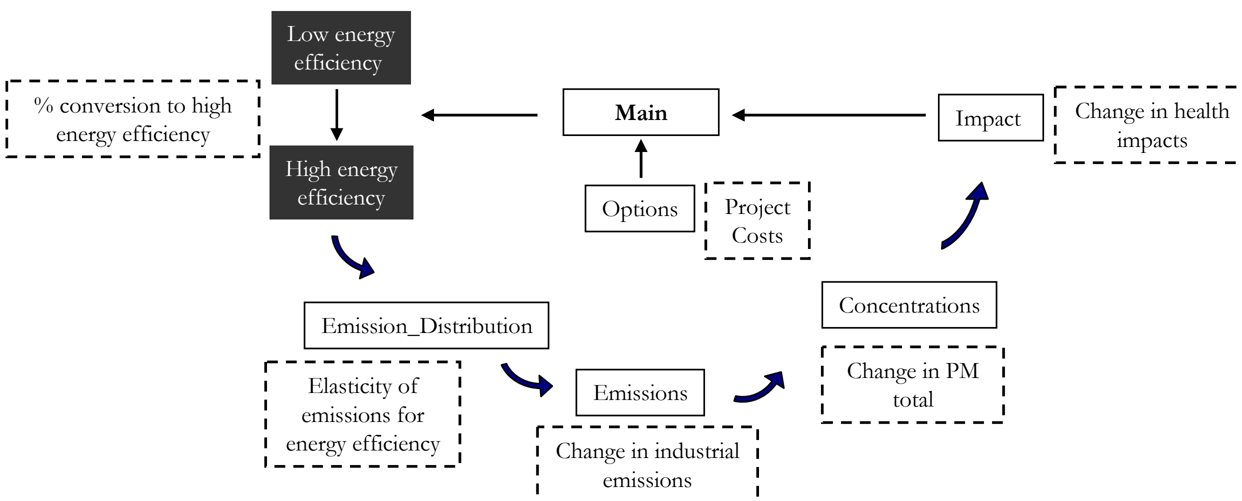


Figure 5.5 Changes in the spreadsheet on implementing the option, “Improve energy efficiency in industry”

It is evident that if energy efficiency is not improved and remains as present, there wont be any cost involved. On the other hand, if the industries go for improvement in energy efficiency, the costs involved would increase exponentially with efforts to increase energy efficiency. The costs would vary as follows:

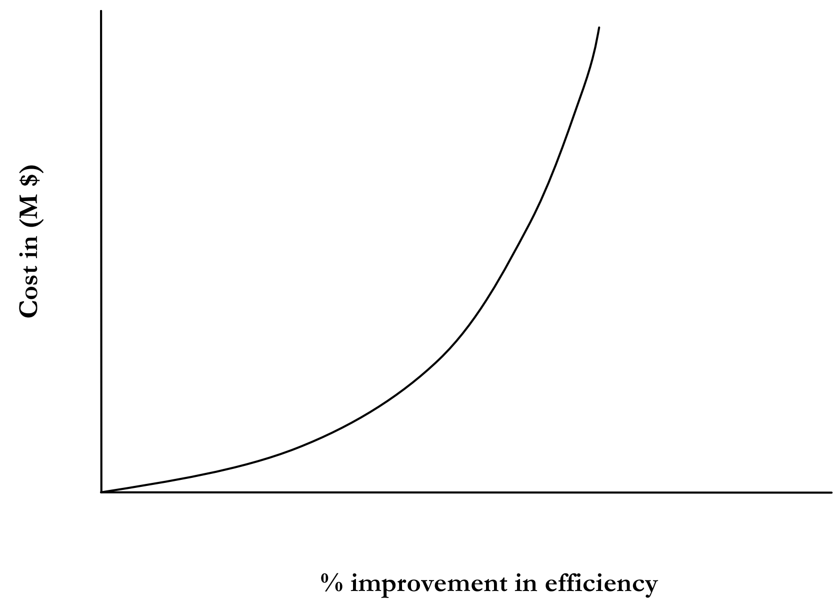


Figure 5.6 Cost curve for the management option, “Improve energy efficiency in industry”

The cost equation based on above graph comes out to be:

$$\text{Cost (M\$)} = A + B \times X^{C}$$

The cost coefficients, A, B and C, for the above equation on the basis of cost-curve were found to be 0, 18.65 and 1.21 respectively.

5.2.4 Shift Industries from C_{23} to C_{33}: Shifting of industries would not result in reduction of annual emission levels, since the emissions from industries will remain same. Emission levels are independent of change in position. However, the health impacts on the community living in the immediate neighborhood of the shifted industries would reduce as follows.

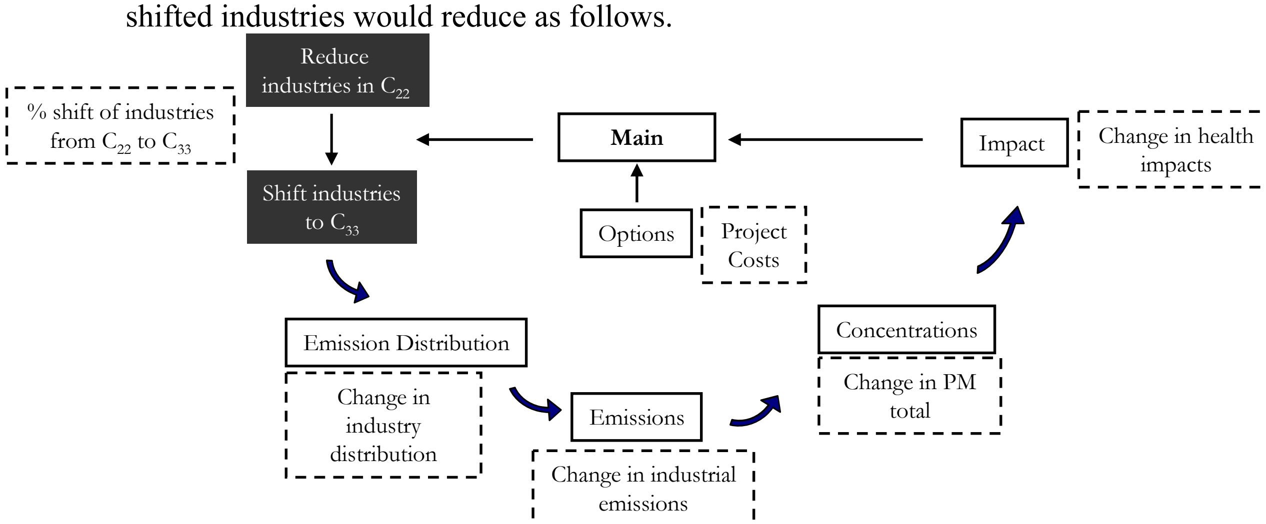


Figure 5.7 Changes in the spreadsheet on implementing the management option, “Shift Industries from C_{23} to C_{33}”

Shifting has to be done keeping in mind the metrology of the considered area as well as the cost implications.

The project costs involved would be necessarily based on comparison of shifting industries in a phase-wise manner. This means that cost of shifting initial 10% of industries will be lesser than that of shifting the remaining industries. As compared to cost of shifting remaining 90% industries, the cost of shifting initial 10% was found to be negligible. Later on, the costs increase exponentially with percentage of industries shifted. The following curve was obtained based on above logic:

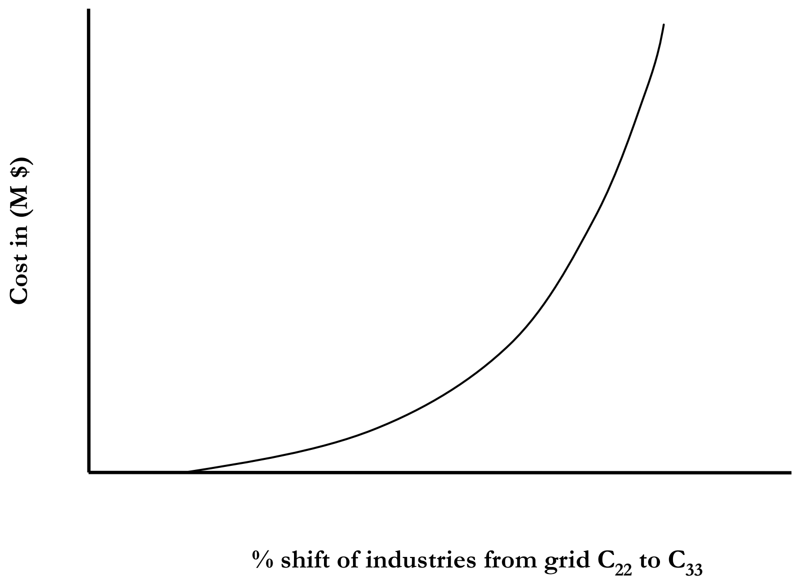


Figure 5.8 Cost curve for the management option, "Shift Industries from C_{23} to C_{33}"

To calculate project costs, cost equation from the above curve is:

$$\text{Cost (M\$)} = A+B\times X^C$$

with cost coefficients as 0, 0.00153 and 3.06 for A, B and C respectively.

5.2.5 Coal to Liquefied Petroleum Gas (LPG) shift in Domestic/Area sources: Burning of coal as fuel in domestic sector leads significant amount of emissions as well as health problems such as asthma and lung cancer in acute cases. The problem persists particularly in rural sector of developing and poorer nations. In order to reduce emissions from domestic sources on account of usage of coal, a strategy could be to replace coal with LPG. This will in turn reduce severe health impacts as follows:

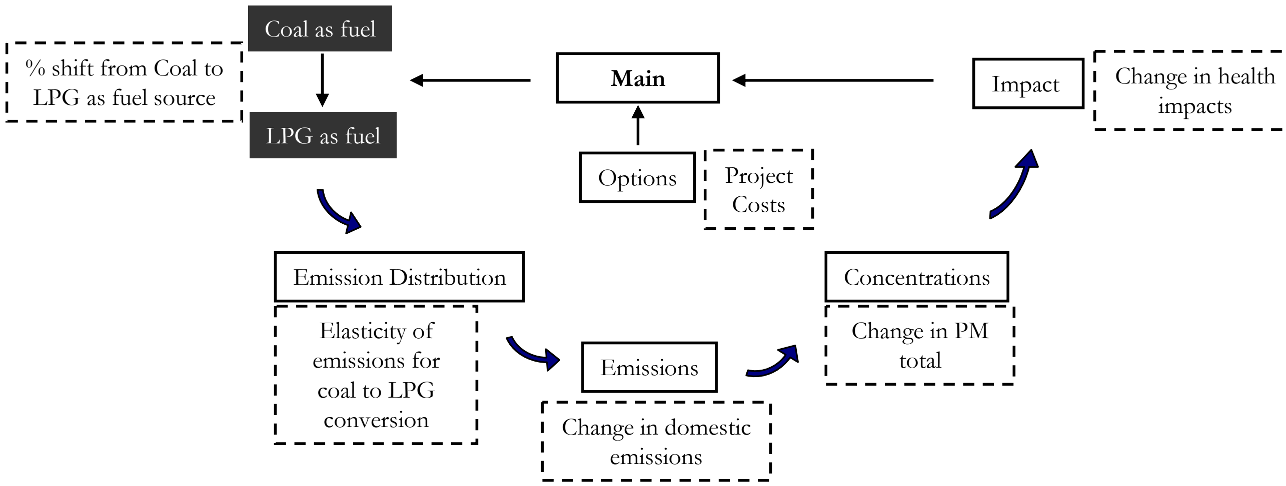


Figure 5.9 Changes in the spreadsheet on implementing the option, "Coal to LPG shift in domestic/area sources"

To account for the costs involved in the project, logic similar to that applied in option 'Shift industries from grid C23 to C33' is used. Following curve was obtained:

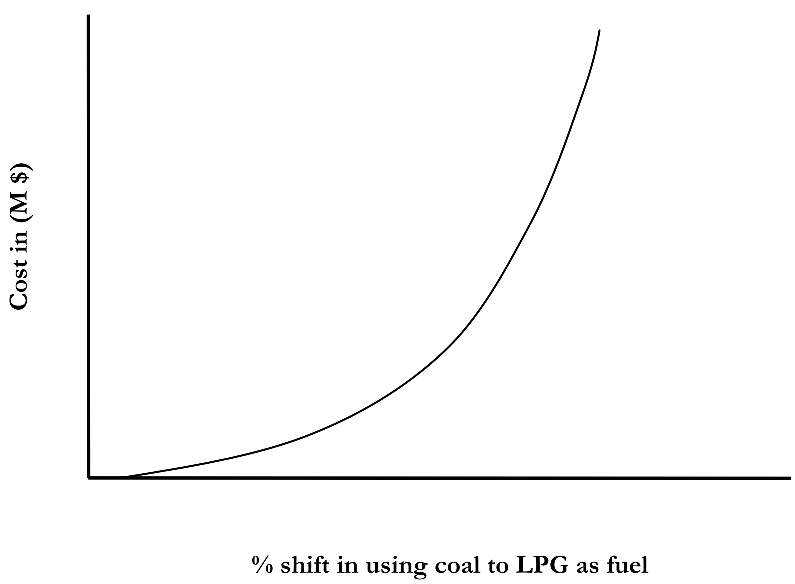


Figure 5.10 Cost curve for the management option, "Coal to LPG shift in domestic/area sources"

On the basis of above curve, the cost equation was modeled to be quadratic with cost coefficients A, B and C as 0, 1 and 0.75 respectively:

$$\text{Cost (M\$)} = A+B\times X+C\times X^2$$

5.2.6 Scrappage (2-stroke motorcycles to 4-stroke): The older 2-stroke engines are not only inefficient in terms of fuel consumption, but also produce large amount of emissions such as SOx and NOx. Voluntary or mandatory retirement of vehicles running on 2-stroke engines is one of the strategies to reduce emissions. Several scrappage programs aided by leading funding agencies such as the World Bank were implemented world wide. Users and owners of 2-stroke engines were encouraged to retire their vehicles and shift to 4-stroke vehicles. Newer models of 4-stroke engines are not only fuel efficient but also produce lesser emissions as compared to 2-stroke engines thereby reducing health impacts:

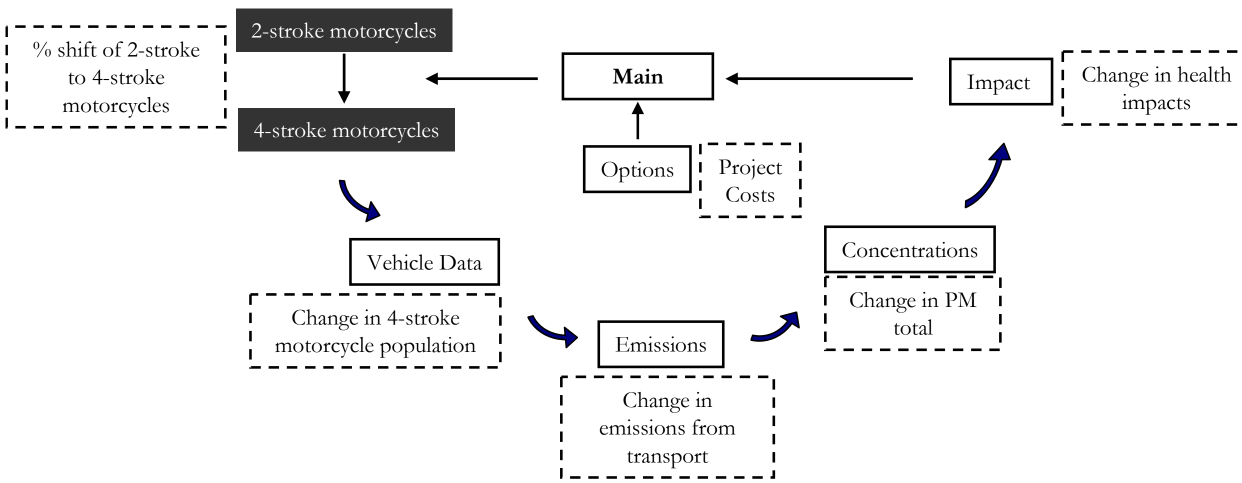


Figure 5.11 Changes in the spreadsheet on implementing the management option, **"**Scrappage (2 stroke to 4 stroke)"

To account for the costs involved, costs of various projects implemented by multilateral funding agencies were compared and following cost curve was obtained:

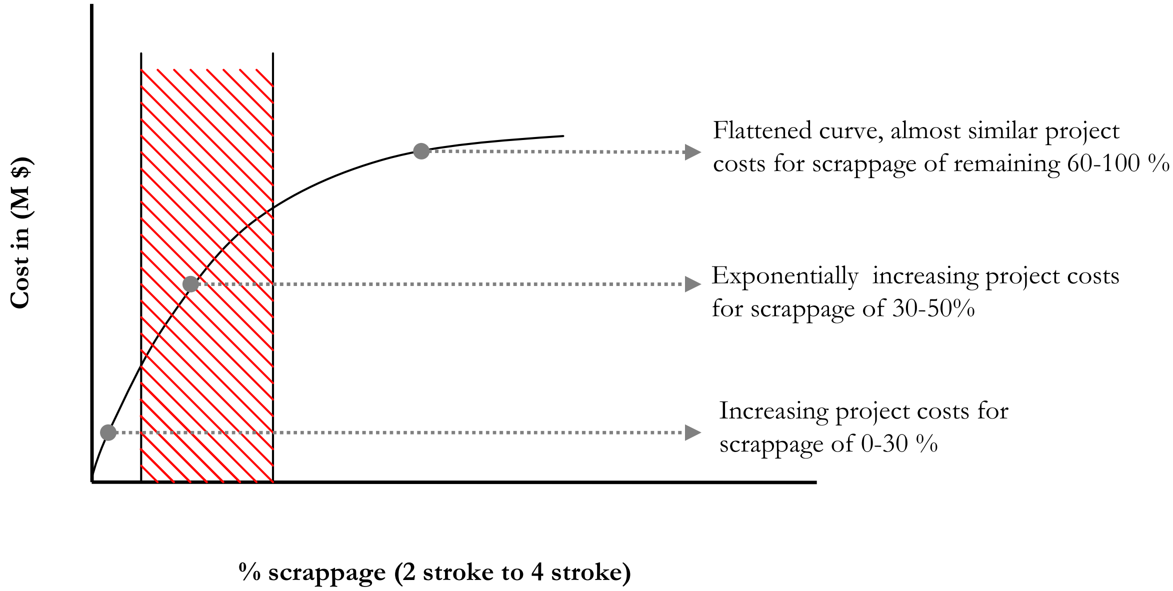


Figure 5.12 Cost curve for the management option, "Scrappage (2 stroke to 4 stroke)"

The costs equation can be modeled as quadratic function as follows:

$$\text{Cost (M\$)} = A+B\times X+C\times X^2$$

Comparing various projects implemented by multilateral funding agencies, the values of cost coefficients A, B and C came out to be 0, 2.50 and -0.02 respectively.

5.2.7 Trucks using Bypass (through C_{21} not C_{22}): This option is similar to shifting of industries from grid C_{22} to C_{33}. Total annual emissions would be same, but the health impacts on people living in the central grid C_{22} will reduce. This option is necessarily aimed towards reducing health impacts of people living in grid C_{22}. The changes caused by this strategy are depicted in the following schema:

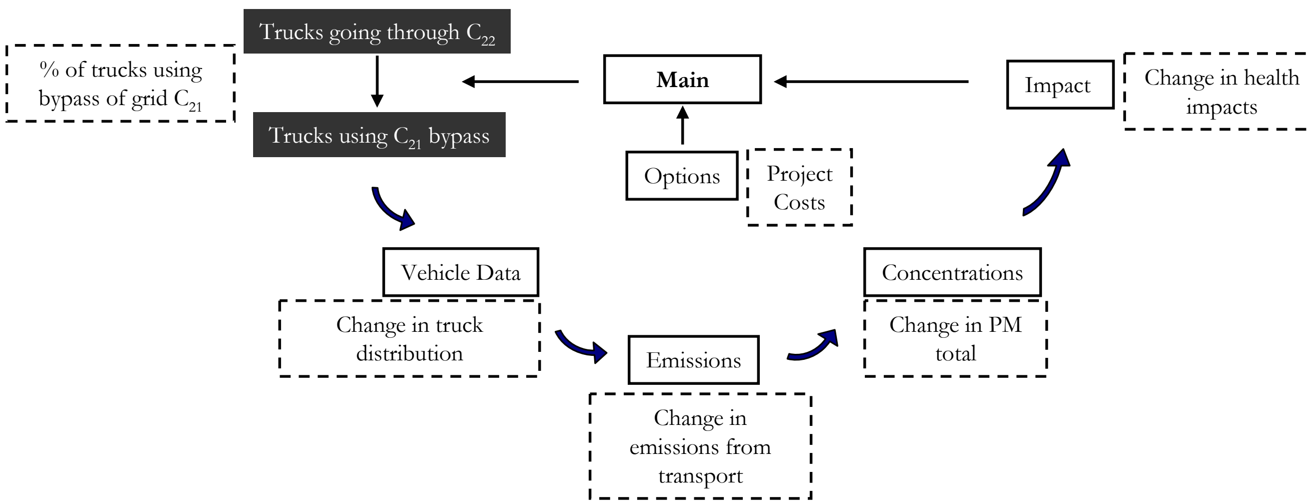


Figure 5.13 Changes in the spreadsheet on implementing the management option, "Trucks using bypass (through C_{21} not C_{22})"

The project costs involved in this option are necessarily management costs to divert initial population of trucks to bypass in grid C_{21}. Hence, the cost to divert initial 15% of truck population will rise steeply. Later on, the cost to divert trucks will not rise rapidly but slowly till it becomes constant after 60%. Following curve is obtained based on the above logic:

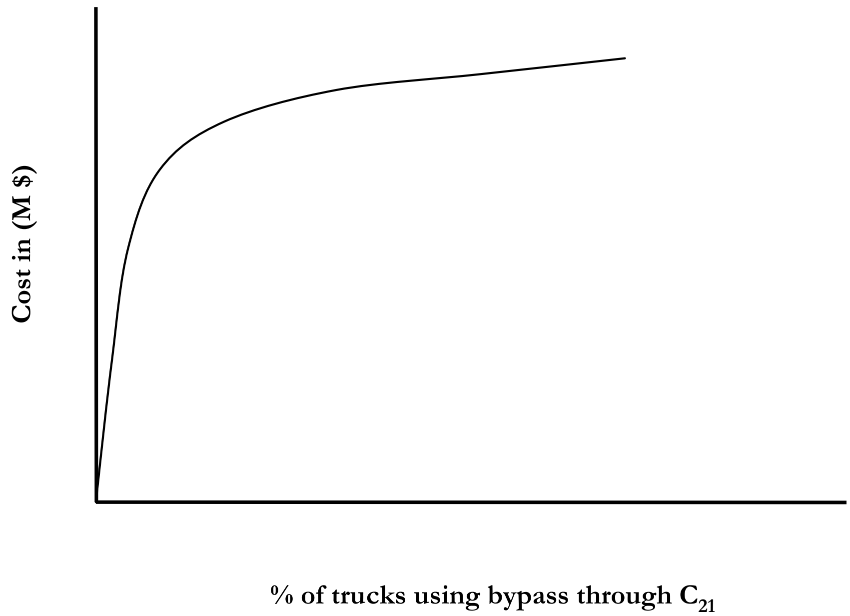


Figure 5.14 Cost curve for the option, "Trucks using bypass (through C_{21} not C_{22})"

The cost equation from the above curve comes out to be exponential:

$$\text{Cost (M\$)} = A + B \times X^{C}$$

The values of cost coefficients A, B and C were found to be 0, 21.86 and 0.18 respectively:

5.2.8 Encourage Public Transport (% cars off road): This is one of the most popular strategies aimed at reducing air pollution. More the people use public transport, lesser will be emissions as compared to the case had the same number of people used personal conveyance. In order to implement this option, the public transport system should be improved. This demands infrastructural and financial inputs by concerned authority. The emissions in this case will be function of percentage of cars off road. More the percentage of cars is off road, lesser will be emission levels. Following figure explains the consequences of mentioned change:

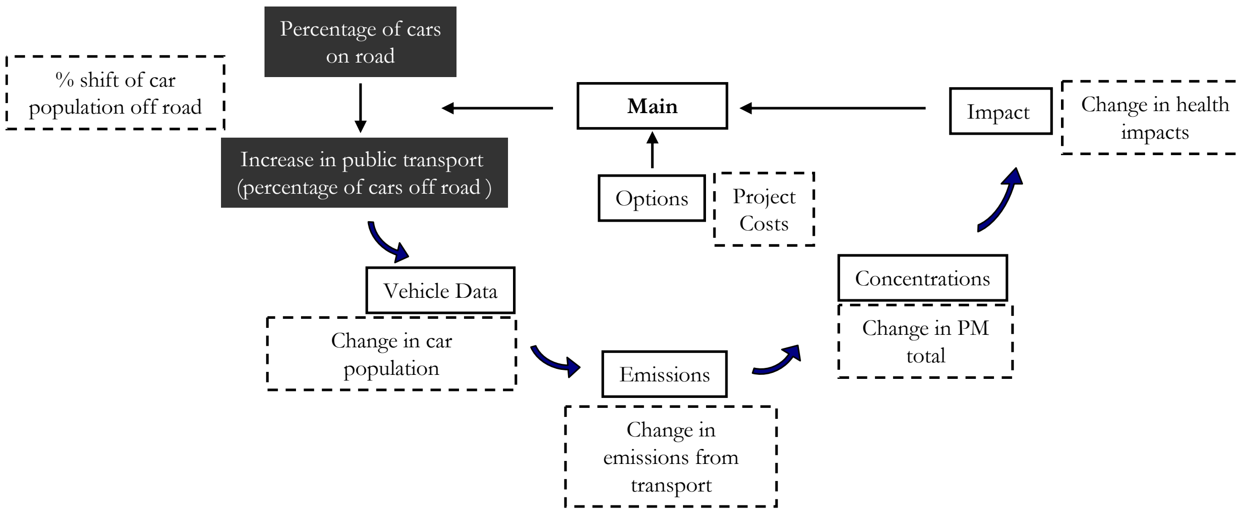


Figure 5.15 Changes in the spreadsheet on implementing the management option, “Encourage Public Transport (% cars off road)”

The cost of implementing this project is necessarily the infrastructural costs on account of increased demand of more number of buses. However it is assumed that the current public transport can accommodate 20% reduction in car use. With each percentage of cars off road, project cost would increase exponentially. Following is the cost curve:

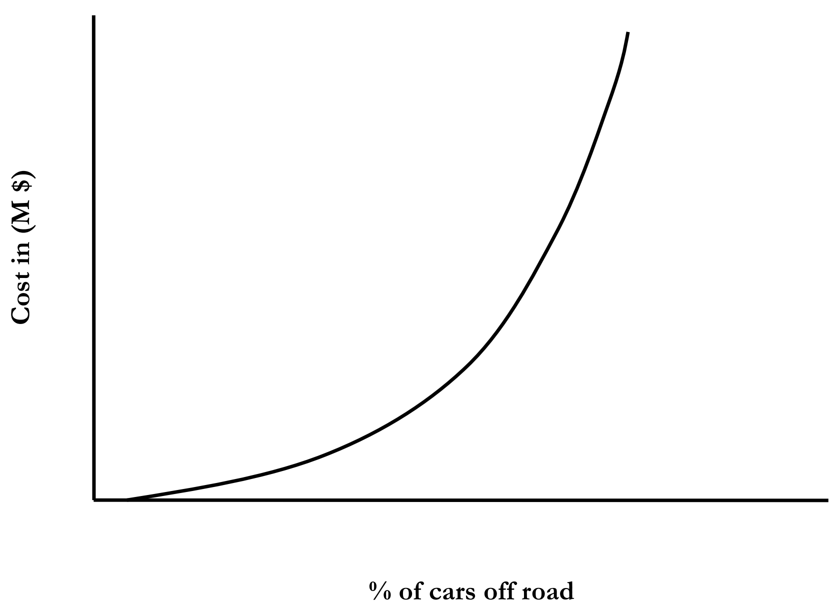


Figure 5.16 Cost curve for the option, “Encourage Public Transport (% cars off road)”

The cost equation based on above curve is as follows:

$$\text{Cost (M\$)} = A+B\times X+C\times X^2$$

Coefficients of above equation based on cost curve are 0, 0.5 and 0.75 respectively.

A summary of above management options along with their cost factors is provided below:

Option	Description	Expected Impact	Modeling Notes	A	B	C	Functional Form (X=scrolled number)
CNG Conversion of Buses (% of Fleet)	Buses converted from diesel to CNG	Reduced particulate emissions as buses change from diesel to cleaner CNG	Diesel bus and CNG bus data in "Vehicle Data" linked	0.00	13.50	-0.06	Cost (M$) = $A+B\times X+C\times X^2$
Low-Sulfur Diesel (ppm reduction of S)	Sulfur levels in diesel reduced to 500 ppm	Diesel vehicles contribute to fewer secondary particulates	Emission factor of SOx of diesel vehicles linked in "Vehicle Data"	-8.75	40,281	-1.11	Cost (M$) = $A+B\times X^C$
Energy Efficiency in Industry	Improve efficiency of energy use - less fuel burned	Industrial emissions reduced as less fuel used	Elasticity used as described in "Emission Distribution" Page	-	18.65	1.21	Cost (M$) = $A+B\times X^C$
Shift Industries from C23 to C33	Move industry from central city areas to periphery keeping in mind wind directions	Reduced emissions in C23; increase in C33	Industry distribution in "Emission Distribution" linked	-	0.00153	3.06	Cost (M$) = $A+B\times X^C$
Coal to LPG shift in Domestic/Area sources	Shift coal use in domestic/area sources to LPG	Reduced emissions due to cleaner fuel use	Elasticity used as described in "Emission Distribution" Page	0	1	0.75	Cost (M$) = $A+B\times X+C\times X^2$
Scrappage (2-stroke motorcycles --> 4 stroke)	Institute scrappage program to exchange 2-stroke motorcycles with 4-stroke ones	Reduced emissions due to switch to cleaner 4-stroke vehicles	2-Stroke and 4-Stroke motorcycle numbers in "Vehicle Data" sheet linked	-	2.50	-0.02	Cost (M$) = $A+B\times X+C\times X^2$
Trucks using Bypass (through C21 not C22)	Trucks going primarily from C31 to C12 are now encouraged to go through C21 and not	Reduced emissions in C22; increase in C21	Truck distribution in "Vehicle Data" sheet linked	-	21.86	0.18	Cost (M$) = $A+B\times X^C$

	the central C22 grid cell						
Encourage Public Transport (% cars off road)	Provide incentives for public to shift from cars to public transport	Reduced emissions as some people switch from cars to public transport	Car numbers in "Vehicle Data" linked; Current public transport capacity assumed to be able to accommodate 20% reduction in car use	0	0.5	0.75	Cost (M$) = $A+B\times X+C\times X^2$

Table 5.1 Sample Management Options

5.3 Adding new management options

Apart from the management options mentioned in the spreadsheet, user can add new management options. In order to add a new management option, all the factors related to the new option should be carefully evaluated. For e.g., the new option could be evaluated as to how it can lead to reduction of particulates. Once all the possible factors are identified, sieving of quantifiable and non-quantifiable options is performed. Quantifiable options are those which can be quantified in terms of costs, health impact etc. Having identified the quantifiable factors associated with the management option, different factors are logically linked to various sections of the worksheet.

As an illustration, consider the following new management option:

"CNG conversion of taxis"

This option is similar to option 1, "CNG Conversion of Buses (% of Fleet)", provided in the spreadsheet. The possible factors associated with this option are:

- Population of diesel taxis converting to CNG
- Population of gasoline taxis converting to CNG
- Reduction in particulate emission
- Willingness to change (since taxis are privately owned and huge initial investments might lead the poorer owners away from change)
- Health impacts
    - Change in total mortality
    - Change in WTP
    - Change in health costs

Out of above factors, following are quantifiable:

- Population of diesel taxis converting to CNG
- Population of gasoline taxis converting to CNG

- Reduction in particulate emission
- Health impacts
    - o Change in total mortality
    - o Change in WTP
    - o Change in health costs

The factors, population of diesel and gasoline taxis will be linked in "Vehicle Data". This in turn will be used to calculate annual ambient concentrations from transport sector and hence the health impacts. Reduction in particulate emission would be observed by changing the percentage of taxis converted. To account for the cost associated with the option, user can follow the logic similar to management option titled, "CNG conversion of buses".

User can follow the steps mentioned below to add new management options:

1. Go to the "Main" worksheet and type the new management option below the existing management options
2. Add the slider: User can add the slider using following steps
    a) Go to "View" menu,
    b) Select "Toolbars"
    c) Click "Forms"
    d) Select "scrollbar" icon from the list
    e) Right click the "scrollbar" and click on "Format Control". Click on "Control" option and assign values to the various parameters of "scrollbar". The options window will appear as follows

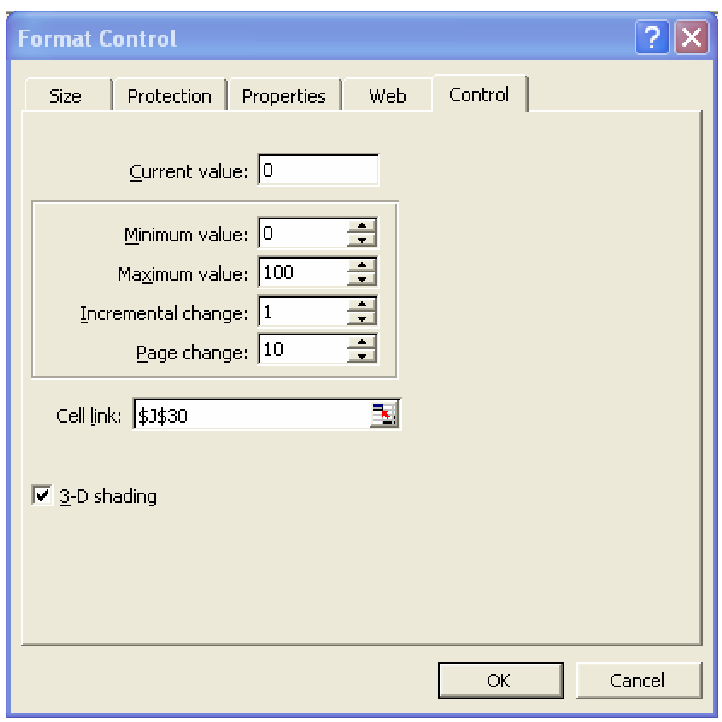


Figure 5.17 Options window

Following are the parameters which appear in the options window:

- Minimum value: Sets a minimum value for the new management option
- Maximum value: Sets the maximum value for the option
- Incremental change: Defines the incremental change
- Cell Link: Links to the concerned cell

3. To include the cost of the new management, perform following steps:
   a) Set the cost equation coefficients[3] namely "A", "B" and "C" for the new management option in worksheet "Options".
   b) Link the "Cost" section in the "Main" worksheet to the cost equation coefficients in the worksheet "Options". To link the cost with the slider bar, the user can perform following steps:
      - In the formula bar, appropriate formula for cost calculation should be entered

The new management options should accordingly be linked to other worksheets such as "Emission_Distribution", "Impacts", "Concentration" etc. based on the following logic:

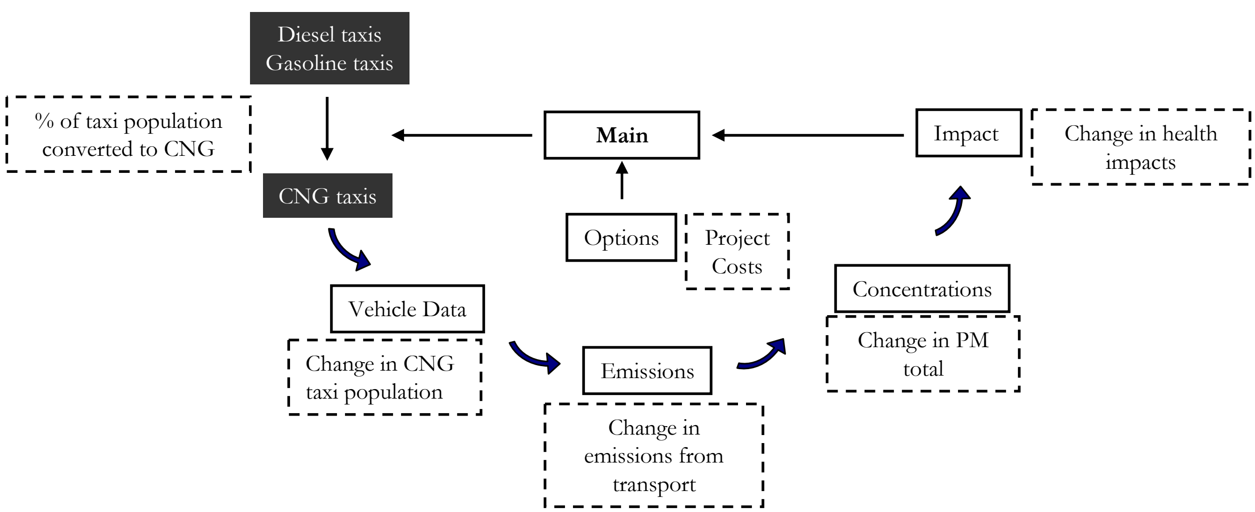


Figure 5.18 Changes in the spreadsheet on implementing the option, "CNG conversion of taxis"

5.4 Using the Optimizer

Optimization tools could be better used in air quality management decision making process. In many ways, optimization illustrates the classic dilemma of decision makers – that of having an objective (or several objectives), and several "knobs" or decision variables for management subject to several constraints. The SIM-AIR has incorporated a

[3] The values of these parameters should be assigned after evaluation of the cost analysis

sample tool to illustrate the use of optimization for air quality management decision making. The form used in SIM-AIR is as follows:

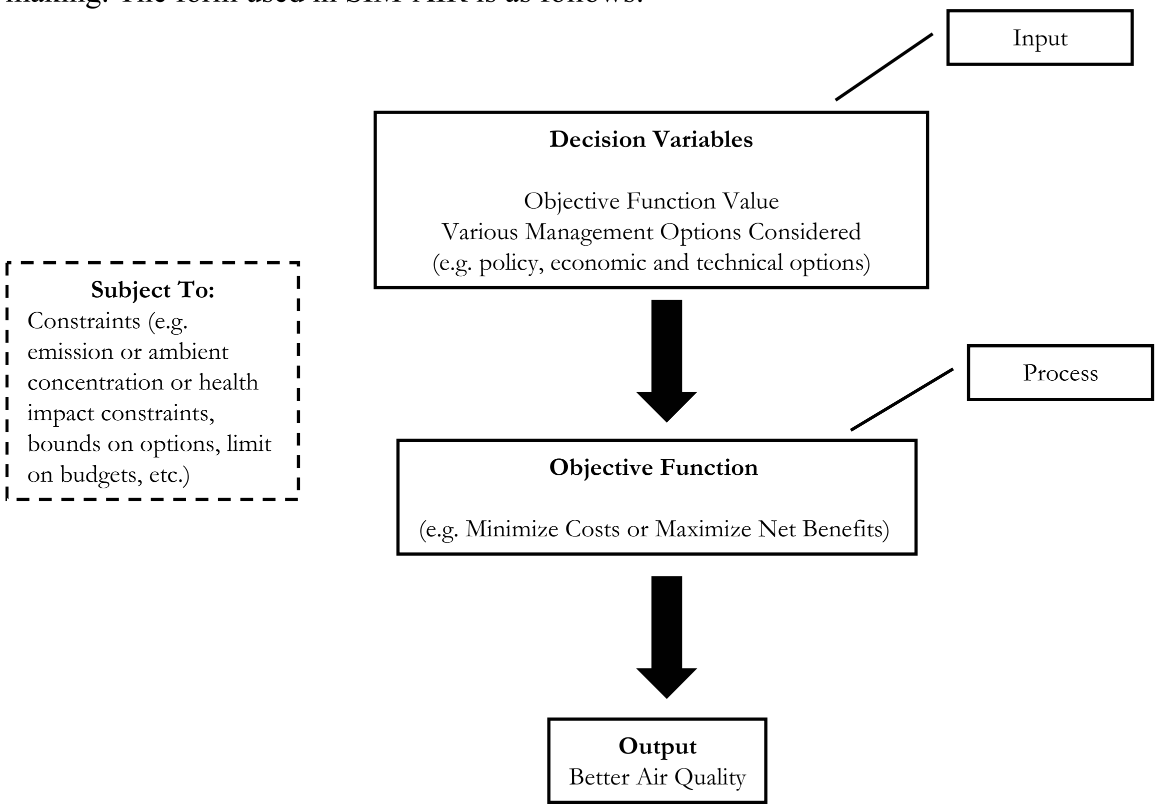


Figure 5.19 Optimization process

- *Objective function:* An objective function is a function that is to be maximized or minimized. For e.g., Minimize costs, maximize benefits
- *Decision variable:* Variable that is under the control of the decision maker and could have an impact on the solution of the problem of interest is termed a decision or control variable. For e.g., Management Options are decision variables.
- *Constraint:* A constraint is a condition that the solutions of an optimization problem must meet, e.g. that a certain decision variable must be greater than zero. Often, constraints are given by equations and inequalities.

Following table lists some of the parameters which can be used in various combinations to arrive at the optimum solution.

Objective Function	Decision Variables	Constraints
Minimum management costs Minimum mortality/morbidity Minimum health effects Minimum ambient concentrations	Management options	Target emission loads • PM10 • SOx • NOx • CO_2 Average regional concentration Grid based concentration Sector based concentration Mortality/morbidity levels Minimum & maximum of management options

Table 5.2 Different parameters of optimization

To illustrate the above concept, let the target envisaged by the planners is to reduce "Total Mortality", then:

Objective function = Minimize total mortality
Decision variables = Various management options
Constraints = Total costs should be less than or equal to Objective cost

The aim is to minimize total mortality using an optimized combination of management options under the cost constraint. The optimized solution can be obtained using the in-built optimization program in Microsoft Excel. This program is known as solver. To use this feature, the user has to follow the steps below:

1. Go to Tools menu and click on Solver
    a. If the Solver is not added in then go to Tools menu and click on Add-Ins and check on the radio-box named "Solver Add-in".
2. A window titled, "Solver Parameters" will pop-up in which various parameters need to filled in.
3. Assign the target as the desired cell.

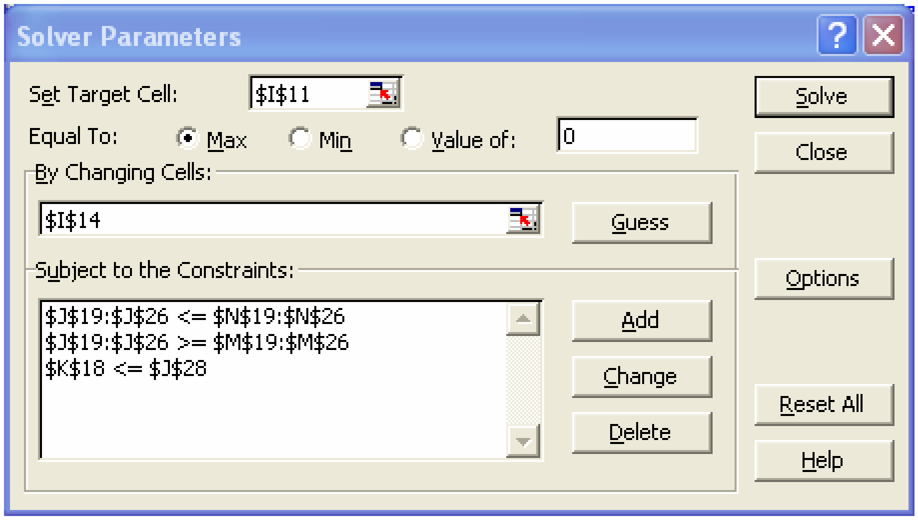


Figure 5.20 Solver parameters

4. Set the constraints in the "Subject to the Constraints" box. As identified earlier, the constraints would be as follows:
   a. Total cost should be less than objective cost
   b. Lower limit of option should always be lesser than lower limit of the option range
   c. Upper limit of the option should always be greater than upper limit of the option range

   More number of constraints can be added by clicking on Add
5. Decision variables can be filled in the box titled, "By Changing Cells:"
6. Click on "Solve" to get the optimized result.

The tools mentioned in this section are some of the sample tools which can be used in decision support systems such as SIM-AIR. As the user gets hold of spreadsheet, he/she can append/amend the data as per required.