CHAPTER 3

METHODOLOGY

3.1 Preamble

The research study consists of 2 parts, qualitative and quantitative perspectives, with application of pollution prevention technique. Qualitative part identifies root cause analysis and generation& selection of alternative solutions. Whereas the quantitative part is integration of transport methodology and vehicle emissions with GIS application for data presentation, as shown in the framework of methodology as demonstrated in Figure 3.1. The research methodology was divided into two main phases:

3.2 Phase 1: Developing air pollution prevention technique for transport sector

Developing air pollution prevention techniques for transport sector was undertaken by applying pollution prevention technique of U.S. EPA as stated in Section 2.2. Principle step of pollution prevention technique of U.S. EPA was stepwise applied to pollution prevention techniques for air pollution prevention of transport sector in this study as illustrated in Figure 3.2 and subsequently explained herein.

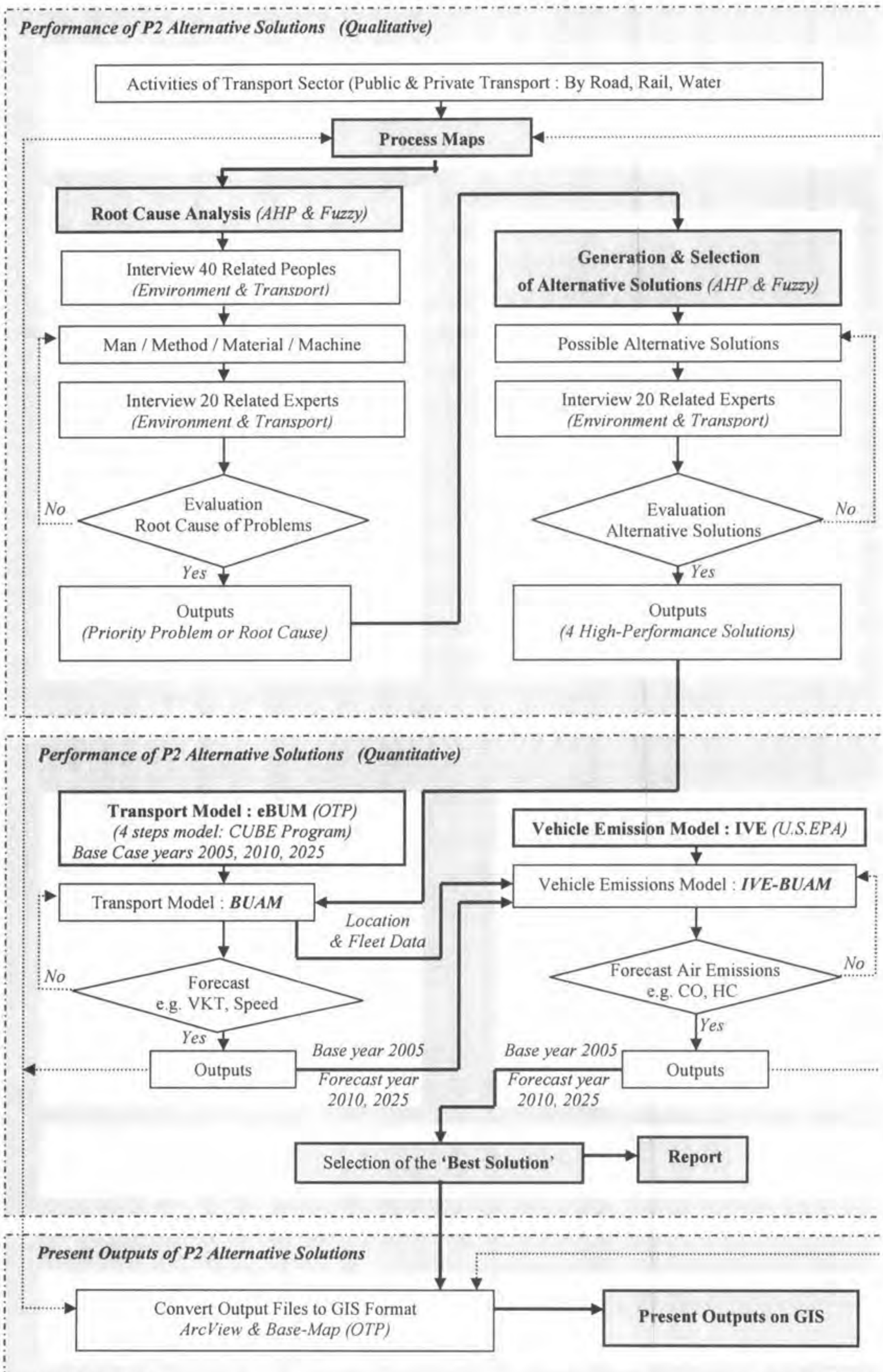

Figure 3.1 Framework of methodology

3.2.1 First step: Process mapping

It explains the steps that people start travel from the origin passing through the way to the destination. Process map allows a person trip to identify all activities and outputs from origin to the destination, where and which activities pollute air emissions, and leads to a better understanding of all activities. This process map can serve as templates for clarify the activities based causing from transportation sector.

Clarifying all activities of transport sector in the Bangkok urban area by using the applied process map is shown in Figure 3.3.

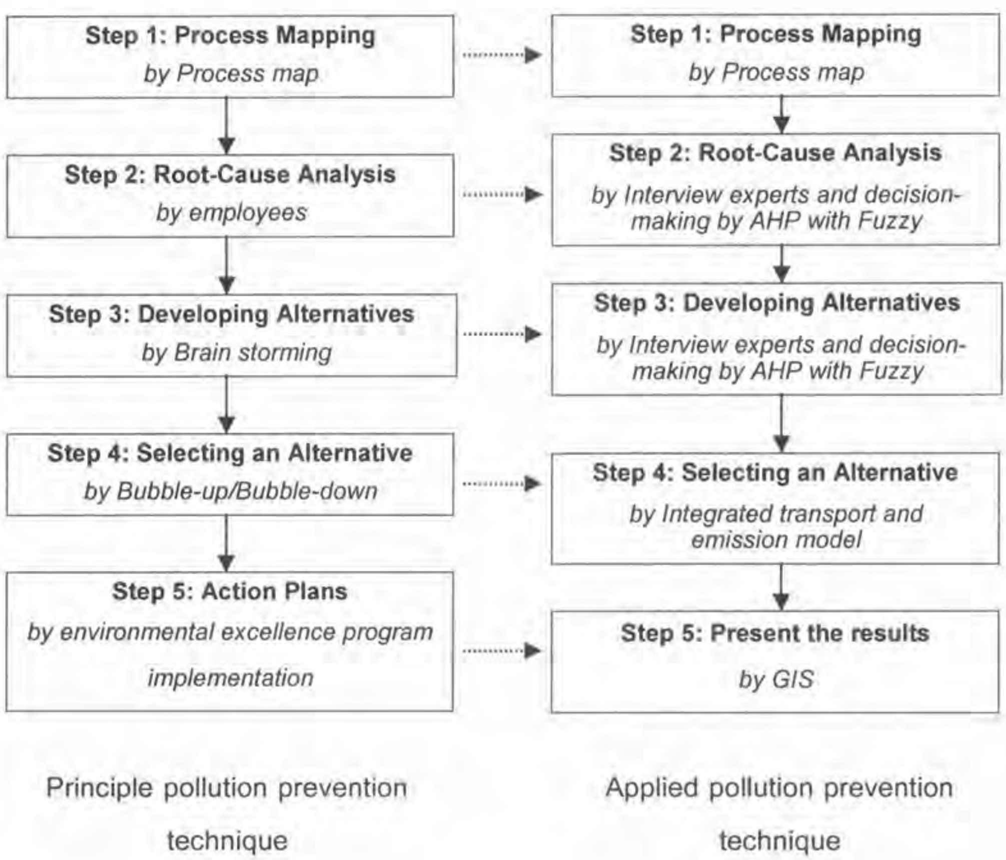

Figure 3.2 Principle and applied pollution prevention technique

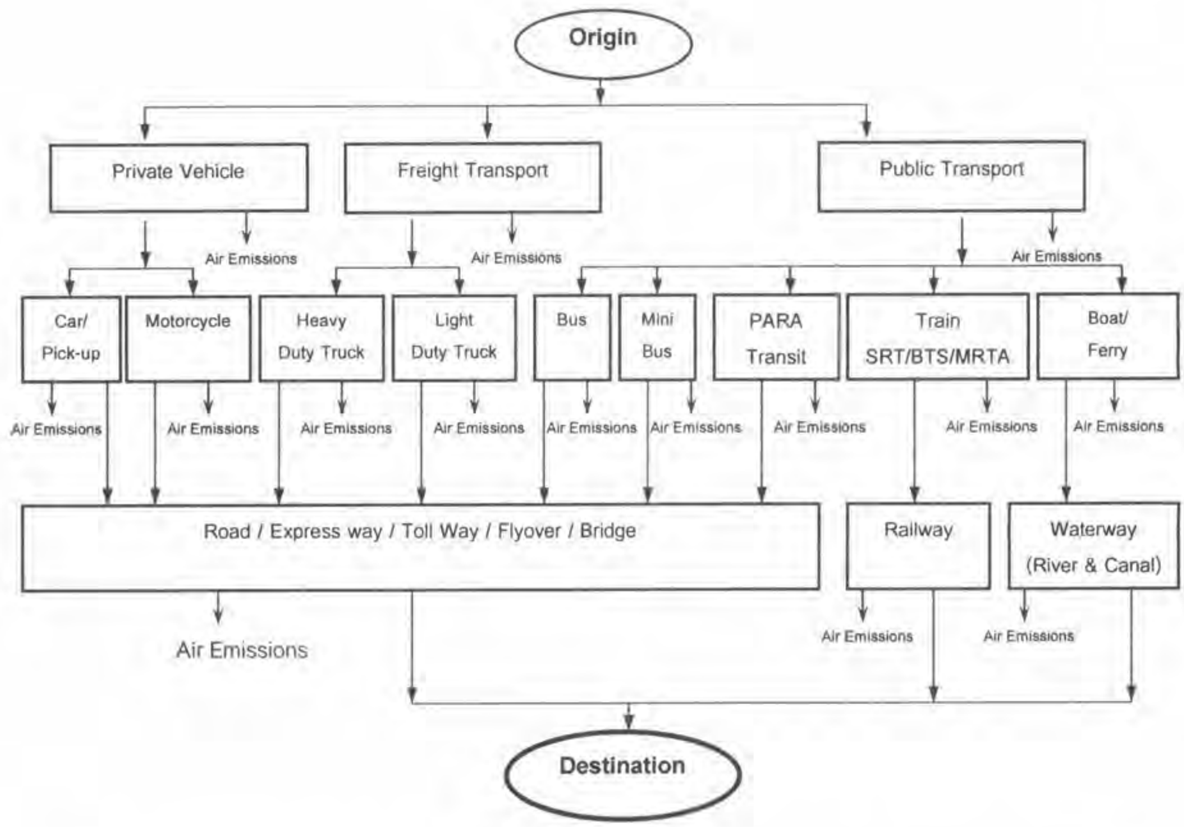

Figure 3.3 Process map of all activities of transportation sector in the Bangkok urban area

3.2.2 Step 2: Root-cause analysis

This step focuses to the nature of the problem. The analysts employ a cause and effect diagram that highlight why and where emits air pollutions in a process. This information will help analyst focusing on the specific areas for improvement. Root cause analysis promoted discussion and helped gathering information on problems from a complete range of possible contributing factors, including man, methods, machines, and materials. Root cause analysis was undertaken as follows.

Firstly, interviewing the focus group of 40 people who work related to the environmental and transportation sectors in Thailand , including the Ministry of Natural Resources and Environment, Ministry of Transport, Police Department, Universities and other related organization to identify the causes of problems.

In this study, 40 interviewers were randomly selected from the decision maker group as shown in Table 3.1. These target samples were interviewed to obtain the causes of air emission generated from transportation sector through pollution prevention approach based on the components of man, method, machine, and material.

Secondly, interviewing 20 experts who are related to the environmental and transportation sectors by used a multi-criteria analysis (AHP and Fuzzy software programs). These 20 experts were interviewed twice time, first to identify the priority problem, second to generate alternative solutions and ranking for 4 high-potential alternative solutions by;

- Interviewing 20 experts from the Office of Natural Resources and Environmental Policy and Planning, Pollution Control Department, Office of Transport and Traffic Policy and Planning, Land Transport Department, Police Department, Universities and other relater organization.

Table 3.1 Focus group of 40 samples related to the environmental and transportation sectors

Organization	Agencies	Experience	No. of Sample
Ministry of Natural Resources and Environment	Pollution Control Department (PCD)	Environmental (Air pollution)	5
	Department of Environmental Quality Promotion (DEQP)	Environmental (Air Pollution)	5
Ministry of Transport	Office of Transport and Traffic Policy and Planning (OTP)	Transportation and Environmental	3
	Department of Land Transport (LTD)	Transportation and Environmental	3
Police Department	Traffic Police Department	Transportation and Traffic	2
		Transportation and Traffic	2
Universities	Chulalongkorn University	Environmental	4
	Asian Institute of Technology	Environmental	2
	Kasetsart University	Environmental	2
	Mahidol University	Environmental	2
	Thamasart University	Environmental	2
Other related Organization			
Asian Development Bank (ADB)	Urban and Environment Sector	Environmental	2
Bangkok Metropolitan Administration (BMA)	Traffic and Transportation Bureau.	Transportation And Traffic	2
	Environment Sector	Environmental	2
United Nations Development Program (UNDP)	Environment Sector	Environmental	2

In this study, 20 experts were randomly selected from the decision making group. The requirements of each expert have to graduate in doctoral degree for at least 15 years. In case if the expert who did not graduate in doctoral degree, the expert have to have experiences in the field of transportation or environmental for at least 20 years. Table 3.2 shows the numbers of the experts selected from each group. These experts were interviewed to obtain the priority problem or root cause and 4 high-potential alternative solutions.

- All of potential alternative solutions are described by incorporating environment impacts, implementation impacts, economic impacts, and people & public impacts (social impacts).

Table 3.2 Experts of 20 samples related to the environmental and transportation sectors.

Organization	Agencies	Experience	No. of sample
Ministry of Natural Resources and Environment	Pollution Control Department (PCD)	Environmental (Air pollution)	2
	Department of Environmental Quality Promotion (DEQP)	Environmental (Air Pollution)	1
Ministry of Transport	Office of Transport and Traffic Policy and Planning (OTP)	Transportation and Environmental	2
	Department of Land Transport (LTD)	Transportation and Environmental	1

Table 3.2 (Cont) Experts of 20 samples related to the environmental and transportation sectors.

Organization	Agencies	Experience	No. of sample
Police Department	Traffic Police Department	Transportation and Traffic	1
		Transportation and Traffic	1
Universities	Chulalongkorn University	Environmental	2
	Asian Institute of Technology	Environmental	2
	Mahidol University	Environmental	2
	Kasetsart University	Environmental	1
	Thamasart University	Environmental	1
Other related Organization			
Asian Development Bank (ADB)	Urban and Environment Sector	Environmental	1
Bangkok Metropolitan Administration (BMA)	Traffic and Transportation Bureau.	Transportation And Traffic	1
	Environment Sector	Environmental	1
United Nations Development Program (UNDP)	Environment Sector	Environmental	1

Criteria and selection of priority problem or root cause of air emissions generated from transportation sector.

In this step, multi criteria analysis was performed by Analytic Hierarchy Process (AHP) and Fuzzy program. This AHP method is widely use in complex and intangible decision making problems in various areas of requirement and interests. In traditional AHP in order to obtain the optimal overall decisions, AHP requires structuring, weighting as well as synthesis procedures. In this study, a hierarchy structure was established with four criteria and eight factors to select the greatest finite alternatives in priority problem and alternative solutions.

Owing to the vagueness of expert judgment, fuzzy set as well as entropy gradating approaches are the main problems or the most appropriate solutions to derive the priority among the alternatives and choosing the desired preference. The hierarchy structure is described in Figure 3.4.

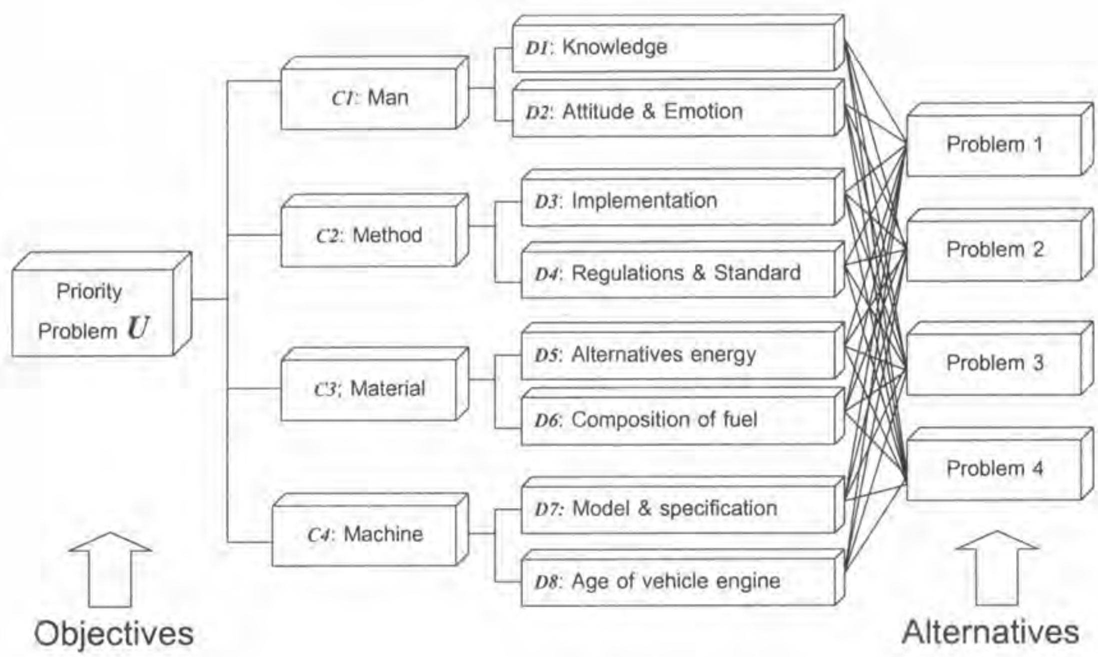

Figure 3.4 Hierarchy structure of selection the priority problem.

There are 4 criteria of 8 factors and 20 problems drawn from the questionnaire used to interview 20 experts by using a multi-criteria analysis (AHP and Fuzzy software programs) to rank and weight the attributes (criteria) for finding the priority problems or root causes from cause-and-effect diagram to clarify the causes of air emissions (man, method, machine and materials) as shown in Table 3.3.

Table 3.3 Definition of factors and qualitative criteria for root cause analysis.

Criteria	Factors	Indicators
Man	Knowledge	Do they have enough knowledge and training equally?
	Attitude & Emotion	How much affected by attitude & emotion?
Method	Implementation	Do they have limited funds and supported? Do they create other problems?
	Regulations & Standard	How much they accepted to the regulation & standard? Do they lack of effective plan, operation and enforcement?
Material	Alternatives	Do they get advantage from alternative fuels or energy? Does it need to change the existing fuels or energy?
	Composition	Do they lack of the competition and innovation in products?
Machine	Model & Specification	Do they use in different of model and engine?
	Age of Engine	How much do they used in different age of engine?

3.2.3 **Step 3: Developing alternatives.** This step employs brain storming from writing of generate as many alternative solutions as possible in order to solve the wastes, emissions, or other losses. This step needs to produce as many as potential solutions. Using the same approach on multi-criteria analysis with AHP and Fuzzy program as illustrated in Figure 3.5. Alternative solutions then were the output of this step.

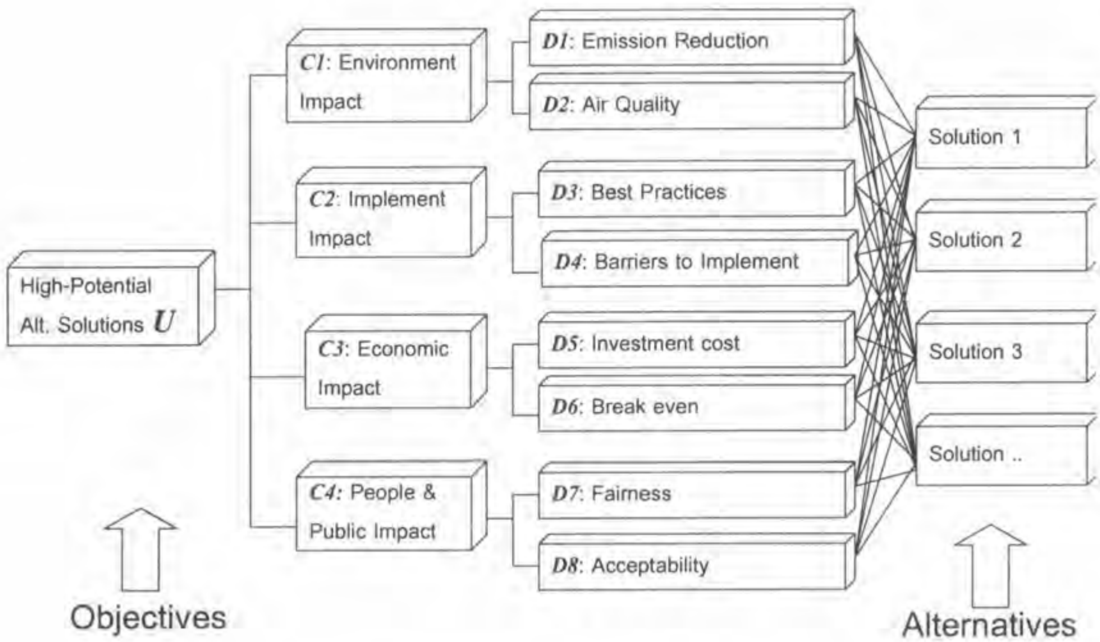

Figure 3.5 Hierarchy structure of selection the alternative solutions

3.2.4 **Step 4: Selecting an alternative** by discussing all alternative solutions like "bubble-up/bubble-down." for prioritize alternatives to determine the optimal solutions for the selected to be best solution. Factors such as cost, ease of implementation, and effectiveness are considered in evaluating and prioritizing the alternative solutions.

Criteria and the selection of best solutions on air pollution prevention from transportation sector were set for this interview. There are 4 criteria with 8 factors and 4 alternative solutions in this questionnaire. Interviewing the same group of 20 experts by using a multi-criteria analysis (AHP and Fuzzy software programs) to give weight and rank the attributes (criteria) that were compared with each pair of alternative solutions in order to select 4 high-potential alternative solutions as shown in Table 3.4.

Table 3.4 Definition of factors and qualitative criteria for select alternative solutions.

Criteria	Factors	Indicators
Environment Impacts	Emission reduction	How much do they reduce the air emission?
	Air quality	How much do they need to have better air quality?
Implement Impacts	Best practices	How much do they think about this solution possible to implementation? How much do they encourage with the other solutions?
	Barriers to implementation	How much are they politically accepted? How much do they need to change the existing institutional practices?
Economic Impacts	Investment cost	How much do they limit funds and support?
	Break even	How much do they meet break even and when?
People & Public Impacts	Fairness	How much do they treat everybody equally?
	Acceptability	How much do they accept the several of people and stakeholders? How much do they need to change the existing situation?

In the above sections 3.2.2, 3.3.3 and 3.3.4, AHP and Fuzzy evaluation were employed as multi criteria analysis approach. Running AHP and Fuzzy program are described below.

In this study, a three-level structure of the hierarchy on the priority problem and alternative solutions evaluation employ the combination of the multiple-criteria analysis with AHP and Fuzzy, which is implemented by executing the following four steps:

Step 1 Determine evaluation criteria set and factors set.

$$U = \{C1, C2, C3, C4\} \quad (19)$$

where:

$$C1 = \{D1, D2\}: \quad (20)$$

$$C2 = \{D3, D4\}: \quad (21)$$

$$C3 = \{D5, D6\}: \text{ and} \quad (22)$$

$$C4 = \{D7, D8\}: \quad (23)$$

U = *objective of the study*

$C1, C2, C3,....,Cn$ = *criteria*

$D1, D2, D3,...,Dn$ = *factors*

Figures 3.4 and 3.5 show the framework of the proposed priority problems and alternative solutions. It is a hierarchical framework with three levels. The first level represents the priority problems and alternative solutions evaluation U. The second level is the evaluation criteria level. The third level is the factors sets.

Step 2 Determine evaluation fuzzy set.

$$V = \{v1, v2, \ldots, vn\} \quad n = 1, 2, \ldots, 5 \qquad (24)$$

where:

V = *set of evaluations*

$v1$ = represents "extreme importance";

$v2$ = represents "importance";

$v3$ = *represents* "moderate";'

$v4$ = represents "indifferent"; and

$v5$ = represents "poor."

Step 3 Obtain weight vector by Analytic Hierarchy Process (AHP).

$$A = \{a1, a2, \ldots, an\} \quad n = 1, 2, \ldots, 10 \qquad (25)$$

where:

$$\sum a_i = a_1 + a_2 + \ldots + a_m = 1 \qquad (26)$$

A = weight vector

$a1, a2, \ldots, an$ = criteria

Step 4 Compute evaluation result.

This step ensures that all factors will be considered completely, which will minimize the information loss to obtain the final evaluation results.

$$B = A \circ R\ \{ej\} = \{e1, e2, e3, e4, e5\} \qquad (27)$$

where:

B = evaluation result

A = fuzzy subset on U (weight vector of U)

R = fuzzy relation on $U \times V$

$e1$ = reflects the degree that evaluation results belong to "extreme importance";

$e2$ = reflects the degree that evaluation results belong to "importance";

$e3$ = reflects the degree that evaluation results belong to "moderate";

$e4$ = reflects the degree that evaluation results belong to "indifferent"; and

$e5$ = reflects the degree that evaluation results belong to "poor."

Consequently, the AHP is based on three steps: (1) decomposition of the decision problem and constructing hierarchies, (2) comparative judgment of the decision elements, and (3) synthesis of priorities. The AHP is used to handle both tangible and intangible criteria and factors affecting fare decision making. At the same time, the relative importance (weights) of all decision elements (i.e., weight vector A) can be explicitly captured and revealed through pair-wise comparison according to the specific scales before determine evaluation grades by fuzzy set .

As presented earlier, the priority problems and alternative solutions evaluation is a decision making that involves value judgment from expert's perspectives.

The proposed AHP comprehensive evaluation combined with fuzzy is a more robust and flexible tool designed to solve decision problems involving multiple factors. Therefore, priority problem and alternative solutions evaluation by used multiple criteria AHP comprehensive evaluation combined with fuzzy are not competitive but complimentary.

3.2.5 Step 5: Present the results obtained from the step 3 the best solution from each step that need to be taken into implementation for reduce the vehicle emissions in the Bangkok area has converted to GIS format.

3.3 Phase 2: Integration of transport and vehicle emission model

Evaluating 4 high-potential of the alternative solutions, which obtained from Phase 1 of the previous step, by integrated the transport and vehicle emissions model as described subsequently.

3.3.1 Modifying the transport model (Extended Bangkok Urban Model: eBUM) from OTP by using CUBE Voyager program to BUAM (Bangkok Urban Area Model) in the base year 2005 and forecast years 2010 and 2025 (before improvement) from OTP, Ministry of Transport. OTP has developed these tools since the year 2004, in order to provide the same tools and database for all related agencies. In addition, the study was use the transport master plan and transport database from OTP Ministry of Transport.

The structure of BUAM can be described as a connection of mathematical models of current traffic conditions and travel behavior that can be used for forecasting of future trips following changes of conditions and population.

The connected models are a Trip Generation Model, Trip Distribution Model, Modal Split Model and Trip Assignment Model as shown in Figure 3.6.

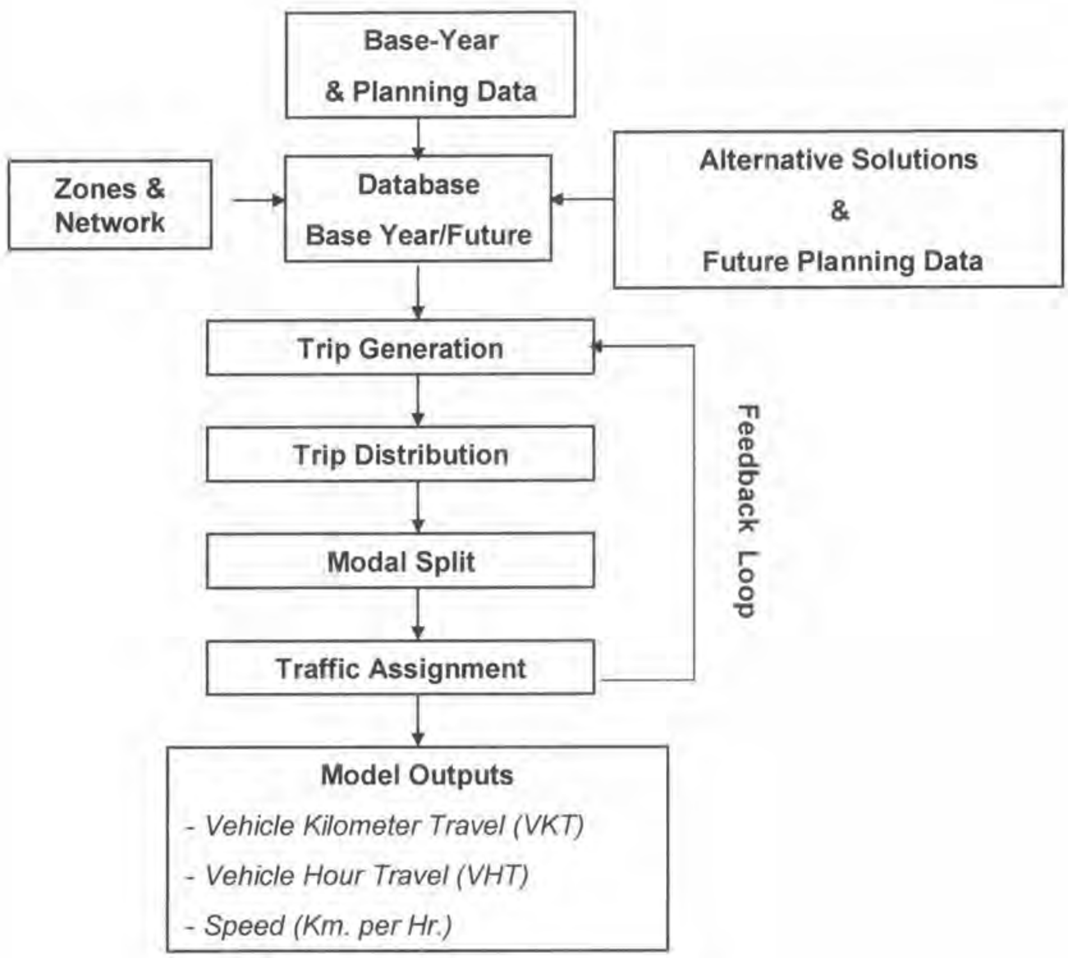

Figure 3.6 Structure of transport four stage model

Figure 3.6 Shows the structure of transport model has four stage approaches as follows:

The Trip Generation Module represents the relationship between trip generation at trip end and other variables of travel. These variables are social and economic characteristics of population and employment as shown in Figure 3.7.

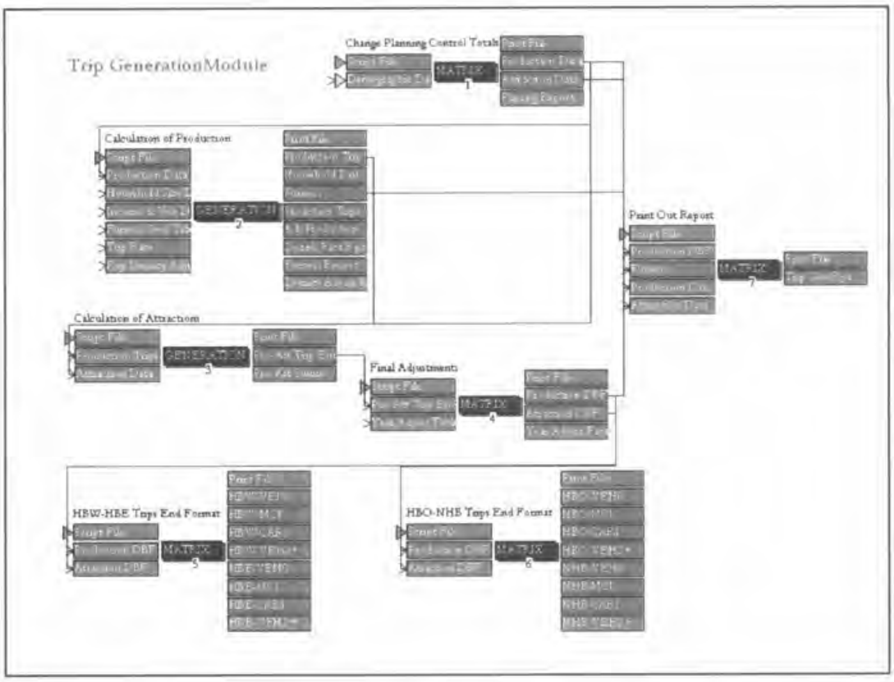

Figure 3.7 Structure of trip generation model used in BUAM

The Trip Distribution Module is used for calculating of trips from one zone to another zone. The result form the analysis shows the trip distribution within the study area that can be applied for forecasting of future trip distribution as shown in Figure 3.8.

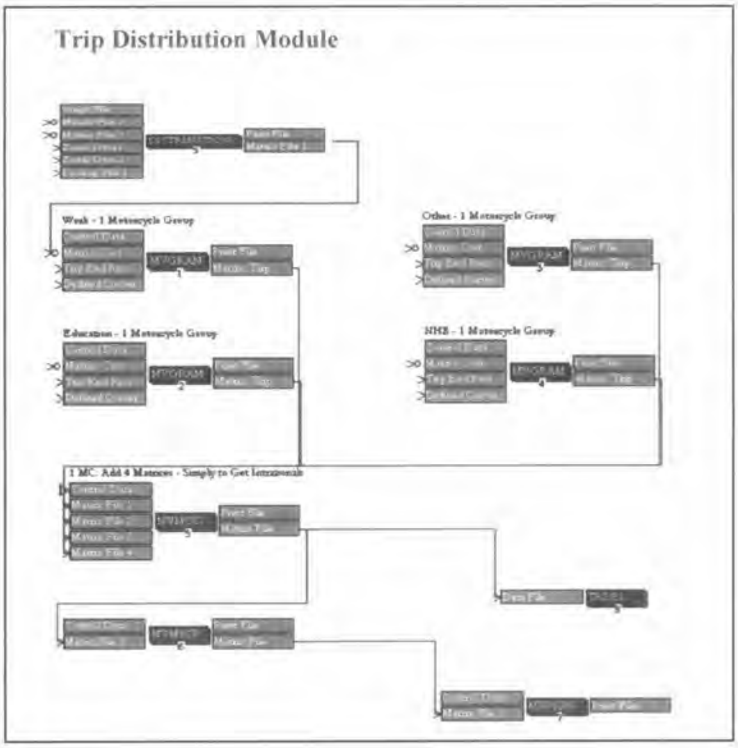

Figure 3.8 Structure of trip distribution model used in BUAM

The Modal Split Module is used to determine the proportion of trips using private and public modes. The result from the analysis can be used for forecasting of future travel by various modes enabling planners to lay down suitable traffic and transport plans as shown in Figures 3.9 and 3.10.

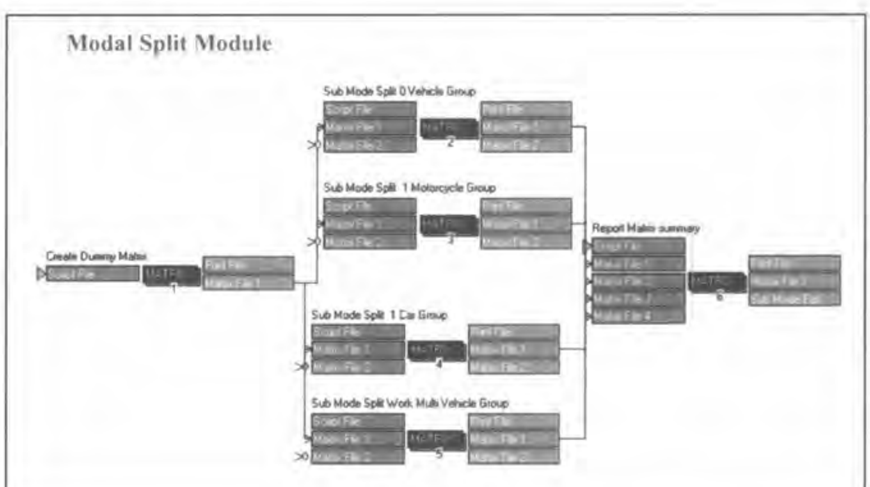

Figure 3.9 Structure of modal split in highway network model used in BUAM

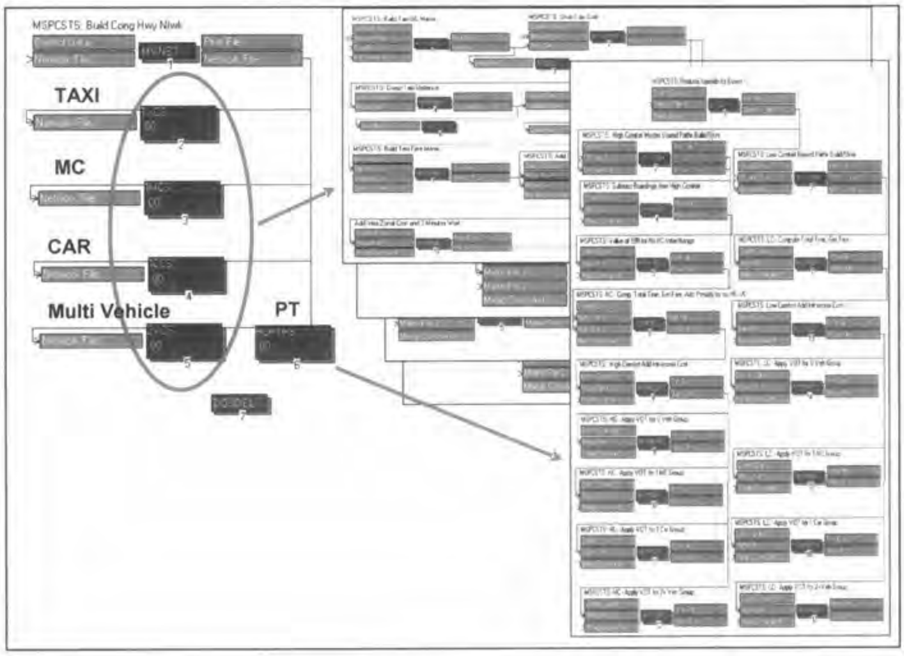

Figure 3.10 Structure of integrated modal split in highway and public transport network model used in BUAM

The Traffic Assignment Module determines the routes and services trips would be base on a relationship between speed and volume of traffic and road capacity as shown in Figures 3.11 and 3.12.

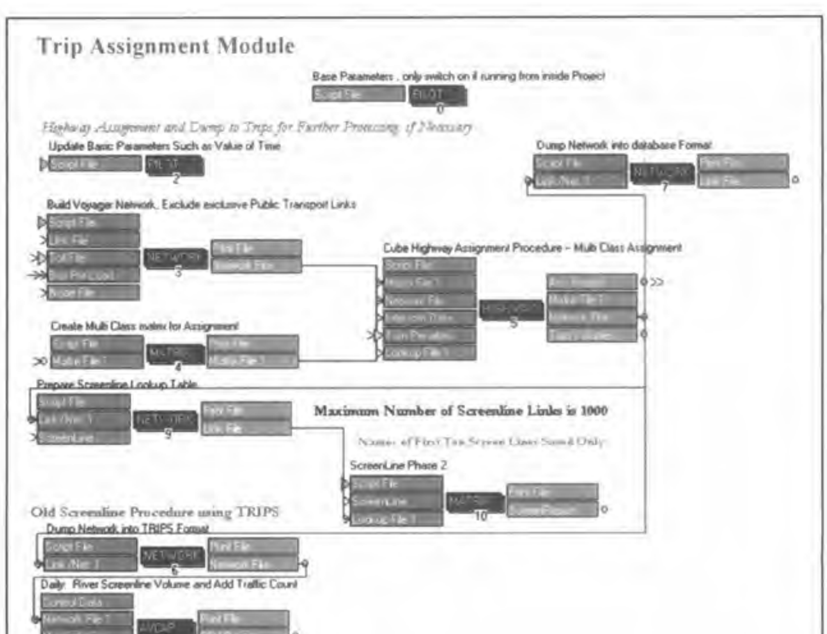

Figure 3.11 Structure of trip assignment model for highway used in BUAM

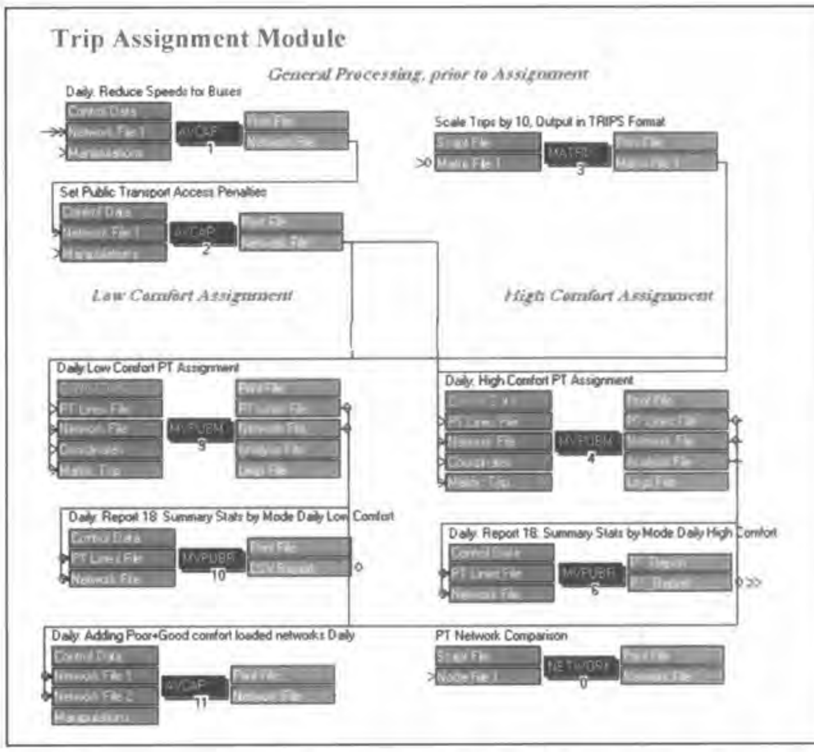

Figure 3.12 Structure of trip assignment model for public transport used in BUAM

This study used the Bangkok urban area model (BUAM) which focuses on Bangkok area. The BUAM was modified from the extended Bangkok urban model (eBUM) which cover all 5 provinces around Bangkok (Nonthaburi, Pathumthani, Samutprakarn, Samutsakorn and Nakhonpathom). The main change are traffic zones from 625 to 430 traffic zones and 5 external traffic zones, and planning data as shown in Table 3.5.

Table 3.5 Planning data for transport model (BUAM)

Parameter	Year		
	2005	2010	2025
Population (million)	8.58	9.35	10.77
Households (million)	1.88	1.97	2.46
Average Household Size	3.62	3.56	3.48

Table 3.5 (Cont) Planning data for transport model (BUAM)

Parameter	Year		
	2005	2010	2025
Average Household Income (Baht)	23,451	28,680	39,097
Employment (million)	3.46	3.59	4.18

Source: OTP 2005

Road Network Characteristics within Bangkok areas are summarized according to their functions and hierarchy as the details in Table 3.6. Summary of road network characteristics is listed from the transport model (BUAM), which was employed in this study.

Table 3.6 Summary of Road Network Characteristics in Bangkok, 2005

Description	Network Distance (Km.)
Non Urban 2 Way - 2 Lanes	4,027
Urban 2 Way - Multi Lanes	3,614
Urban One-way	303
Urban Expressways	660
Dual Carriageway which separated frontage road	116
Major Sois	39
Minor Sois	305

Source: OTP 2005

3.3.2 Modifying the vehicle emissions model by using the International Vehicle Emissions (IVE) model from U.S.EPA to IVE-BUAM (International Vehicle Emissions for Bangkok Urban Area Model) and used Bangkok driving cycles for each type of motor vehicle in Bangkok from OTP and PCD as shown in Figure 3.13.

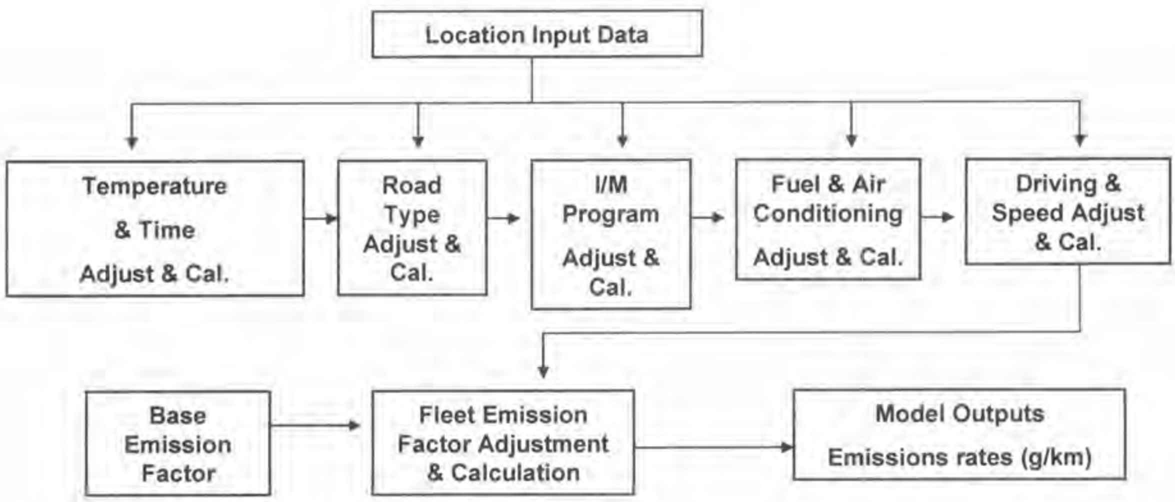

Figure 3.13 Structure of modified IVE model for estimate vehicle emission.

The important input data used in IVE-BUAM are base emission rate and fleet emission factor that was conducted by Clean Development Mechanism (CDM) project in year 2004, The project was conducted driving cycles in Bangkok of 5 types of vehicle including with bus, light duty gasoline, light duty diesel, light duty truck and heavy duty truck, the driving cycles data of 5 types of vehicle as shown in Figure 3.14.

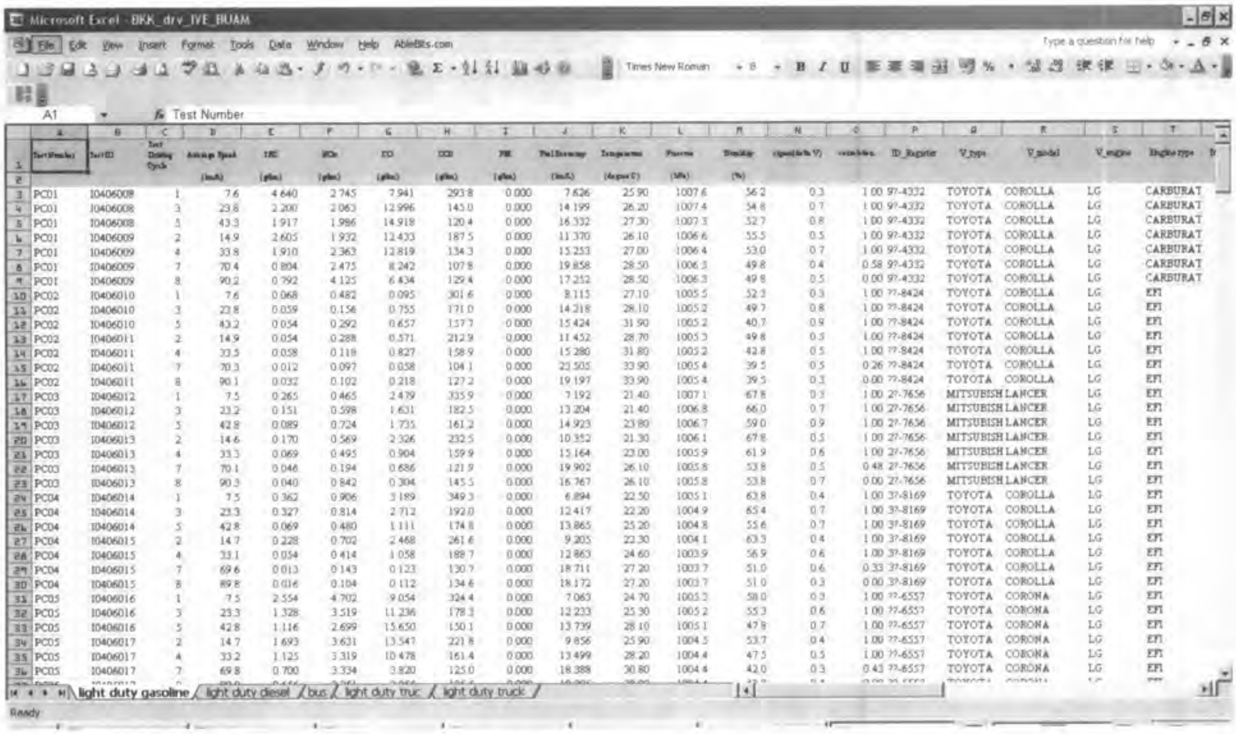

Figure 3.14 Bangkok driving cycles data.

Types and technologies of each vehicle used in IVE-BUAM were adjusted in fleet file templates and technology types of each vehicle as shown in Figures 3.15 and 3.16.

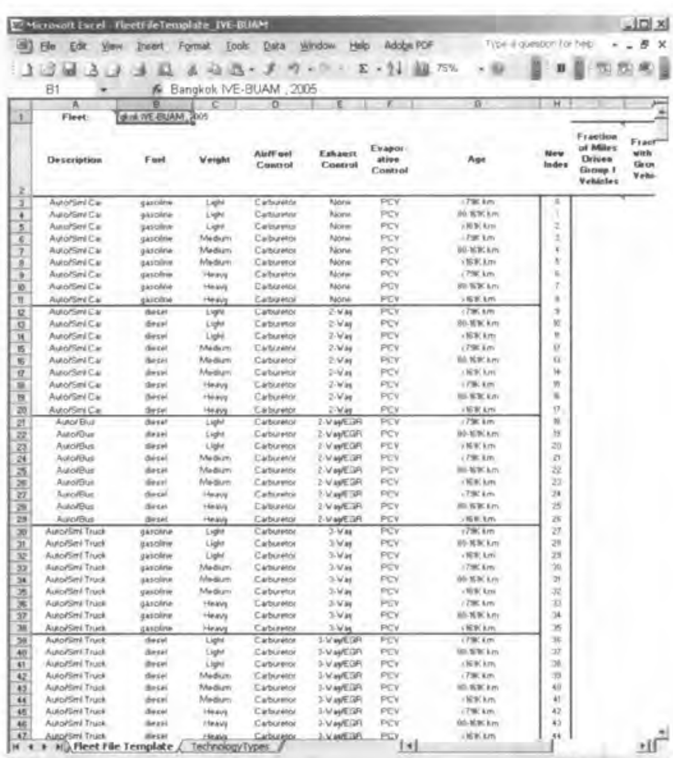

Figure 3.15 Fleet file templates in IVE-BUAM.

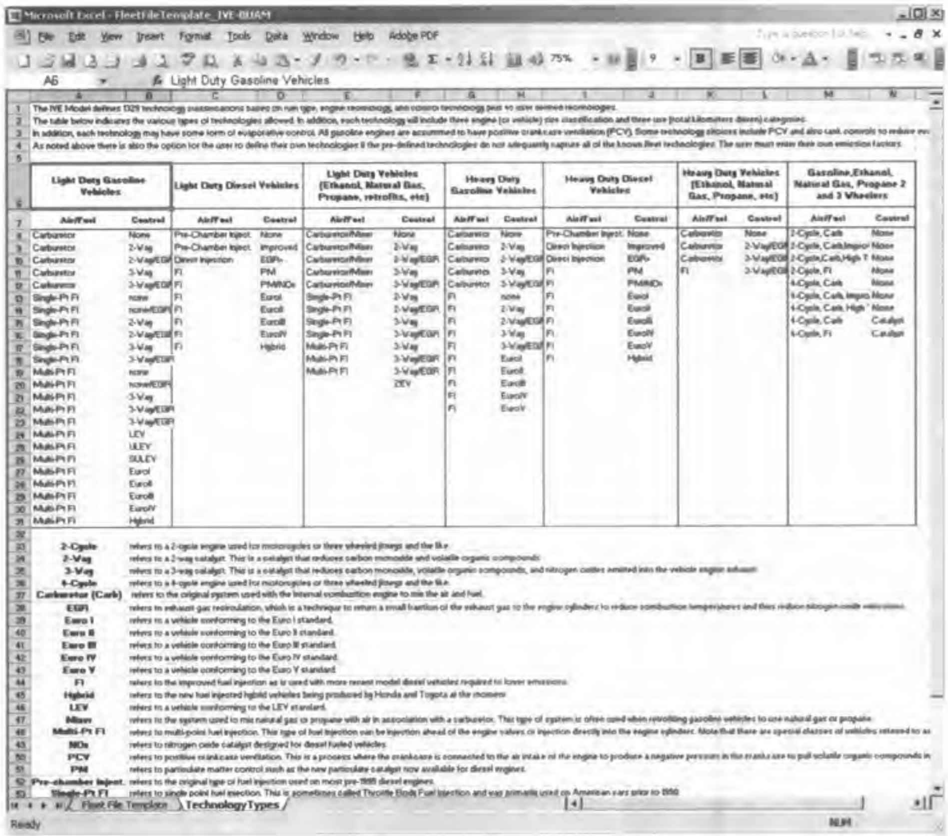

Figure 3.16 Technology types of each vehicle in IVE-BUAM.

3.3.3 Integrated transport model (BUAM) and vehicle emission model (IVE-BUAM) to analysis of 4 high-potential alternative solutions by comparing them with the base case (before and after improvement) in year 2005 and forecast years 2010 and 2025 in morning peak and daily modes, the integrated transport model (BUAM) and emission model (IVE-BUAM) as shown in Figure 3.17.

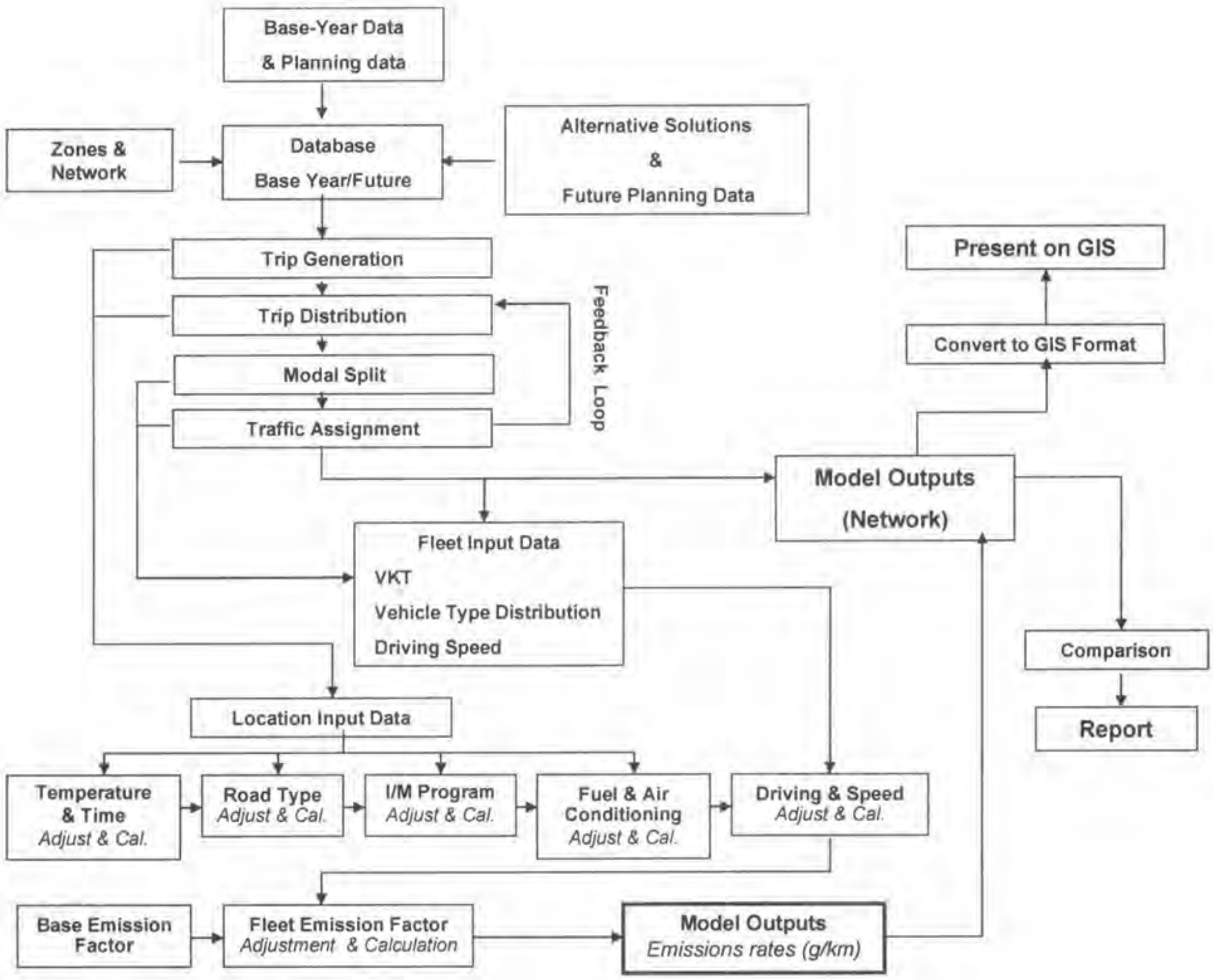

Figure 3.17 Integrated transport model (BUAM) and emission model (IVE-BUAM)

Main location input data of the integrated model (IVE-BUAM) that used in this study as following;

1) Road type imported by trip generation and trip distribution by assigned Capacity Index (CI) to classification with link types in transport model (BUAM) to represent of road type input data as shown in Table 3.7.

Table 3.7 Capacity Index (CI) to classification with link types.

CI (Capacity Index)	Description
1	Special link such as ramps & U-turn
2	1 Lane each way – single carriageway
3	2 Lanes each way (possibly separated carriageways)
4	3 Lanes each way
5	4 Lanes each way – also used where contra-flow in operation
6	One way – I lane
7	One way – 2 lanes
8	One way – 3 lanes
9	Expressway – 2 lanes each way
10	Expressway – 3 lanes each way
11	Expressway – 4 lanes each way
12	Flyover – 1 lanes
13	Flyover – 2 lanes
14	1 Lane each way – traffic calmed
15	One way – 6 lanes (at south end of Ratchadapisek road)
16	5 Lanes each way – also used where contra flow in operation
17	Entry link – as for centroid connectors
18	Centroid (no curve defined and hence free flow speed applies)
19	One way – 4 lanes
20	6 Lanes each way – also used where contra flow in operation

2) Temperature in this study used the average temperature data of Bangkok from Department of Meteorological. The weather station is located at 13.73°N and 100.50°E, 2 meters and 6 feet above sea level. The average daily temperature is 28.1 °C, and average temperature during day time is 32.45 °C.

3) I/M program, vehicle Inspection and Maintenance (I/M) program in this study used data available from Department of Land Transport (DLT) which have regulations for new vehicle that have to test out for the first I/M program after first 10 years and after first 7 years for new motorcycle.

Today's vehicles are absolutely dependent on properly functioning emission controls to keep pollution levels low. Minor malfunctions in the emission control system can increase emissions significantly, and the average in use car on the road emits three to four times off the new car standard. Major malfunctions in the emission control system can cause air emissions. In general, the program usually consists of a periodic emissions test of in-use vehicles, with failing vehicles required to undergo repairs and to pass a retest. After several years of experiences with the wide variety of programs, it is clear that the only effective programs are those in which a centralized facility designed solely to test vehicles using high quality equipment and procedures is the primary testing agent.

Centralized programs involve the testing of vehicles at specialized test facilities capable of handling a high volume of vehicles. Centralized programs may be contractor-run, state-run, or locally-run. A good I/M program will be the backbone of the government's effort to improve particulate and gaseous pollutant air quality over the next several years before new vehicle standards can begin to have any significant effect.

4) Fuel that used in IVE-BUAM was conducted by PTT (PTT Public Company Ltd.). The properties of each fuel as shown in table 3.8.

Table 3.8 Properties of fuel used in IVE-BUAM

Fuel type	Carbon Weight Fraction	H/C Ratio	Density (kg/l or kg/m^3)
Diesel	0.866	1.85	0.840
Biodiesel	0.758	2.19	1.020
Gasoline 91	0.870	1.50	0.744
Gasoline 95	0.886	1.53	0.755
Gasohol 91	0.875	1.84	0.821
Gasohol 95 E 10	0.821	1.98	0.864
Gasohol 95 E 20	0.798	2.56	0.877
Compressed Natural Gas (CNG)	0.590	3.70	0.950
Liquefied Petroleum Gas (LPG)	0.825	2.53	2.020

Source: PTT Public Company Ltd. (2006)

5) Fleet input data of IVE-BUAM imported by output of modal split and trip assignment vehicles are assigned to the three components; (i) highway network including with the cars, taxis, samlors (tuk-tuk), light duty trucks (pick-up), medium duty trucks, and heavy duty trucks on routes which minimize cost, made up of distance, time and toll; (ii) highway network including with motorcycles excluded from expressways, toll way and flyovers; and (iii) public transport including with buses, mini buses, bus rapid transit and mass rapid transit on the fixed routes in public transport network.

Vehicle technology distribution in this study used the vehicle registration data of Bangkok from Department of Land Transport. Table 3.9 presents some of the general characteristics of vehicles in Bangkok.

Table 3.9 General characteristics of vehicles in Bangkok

Type of Fuel	Air Conditioning System	Type of Transmission	Catalytic Converter (CC)
98.5% Gasoline	94% with A/C	32% Mechanic Trans.	97% with CC
1.5% Diesel	6% without A/C	68% Automatic Trans.	3% without CC

Source: Department of Land Transport, (2006)

The technology classifications based on fuel type, and engine technology, Department of Land Transport defined to six most common technology types for gasoline vehicles as shown in Table 3.10.

Table 3.10 Technology fractions of the gasoline vehicles.

Passenger Vehicles	Fraction of vehicles
Gasoline, 4-stroke, Carburetor, No Catalyst	5.04%
Gasoline, 4-stroke, Carburetor, 3-way Catalyst	0.12%
Gasoline, 4-stroke, Single Point Fuel Injection, 2-way Catalyst	9.38%
Gasoline, 4-stroke, Single Point Fuel Injection, 3-way Catalyst	7.03%
Gasoline, 4-stroke, Multipoint Fuel Injection, No Catalyst	0.70%
Gasoline, 4-stroke, Multipoint Fuel Injection, 3-Way Catalyst	77.73%

Source: Department of Land Transport, (2006)

The engine size of the vehicle fleet was generally midsize (1500-2900 cc) and most of the vehicles in Bangkok were low use (<80,000 km). Table 3.11 indicates the engine size and use distribution of the vehicles.

Table 3.11 Size and use characteristics of the vehicles in Bangkok.

Vehicle Engine Size	55% Low Use (<80,000 km)	30% Medium Use (80,000 - 160,000 km)	15% High Use (>160,000 km)
3% Small (<1500 cc)	1.11%	0.27%	0.00%
79% Medium (1500-2900 cc)	63.23%	16.00%	8.49%
18% Large (>2900 cc)	7.24%	2.32%	1.34%

Source: Department of Land Transport, (2006) 3.4 **Phase 3**: Present the results by GIS.

Selecting the best solution in order to minimize the air emissions or to enable the air emission pollutants to meet ambient air standards, and overall outputs of the prevention strategies of air pollution prevention would be converted to present on GIS format (g2sv50.avx) as shown in Figure 3.18.

Figure 3.18 Outputs present on GIS format.

It should be remarked that among other benefits from the methodology used in this study, which pinpoint where the identified pollution prevention strategies should have highest priority for initial implementation.

However, due to the limitation of the input data further than the above mentioned, the default data were taken form each program. For example, Transport model's data used the default data from TDMC5 project of OTP, and emission data used the default data from IVE model.