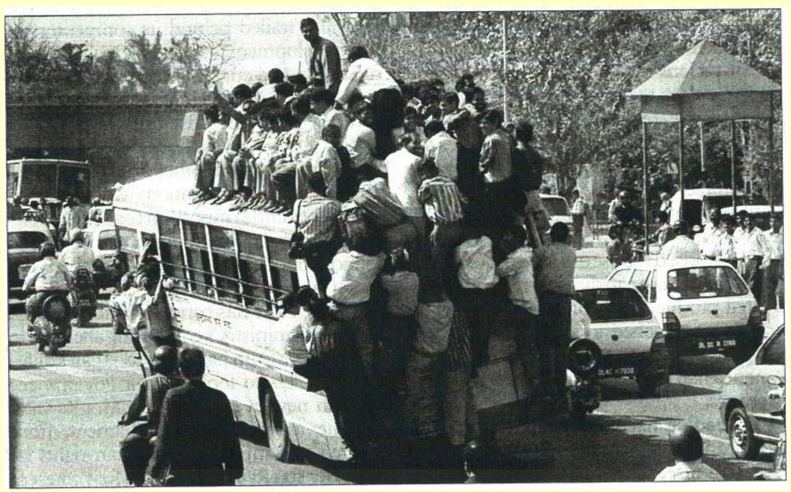
Transportation and Environment

Problems in Delhi



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December 03, 2001

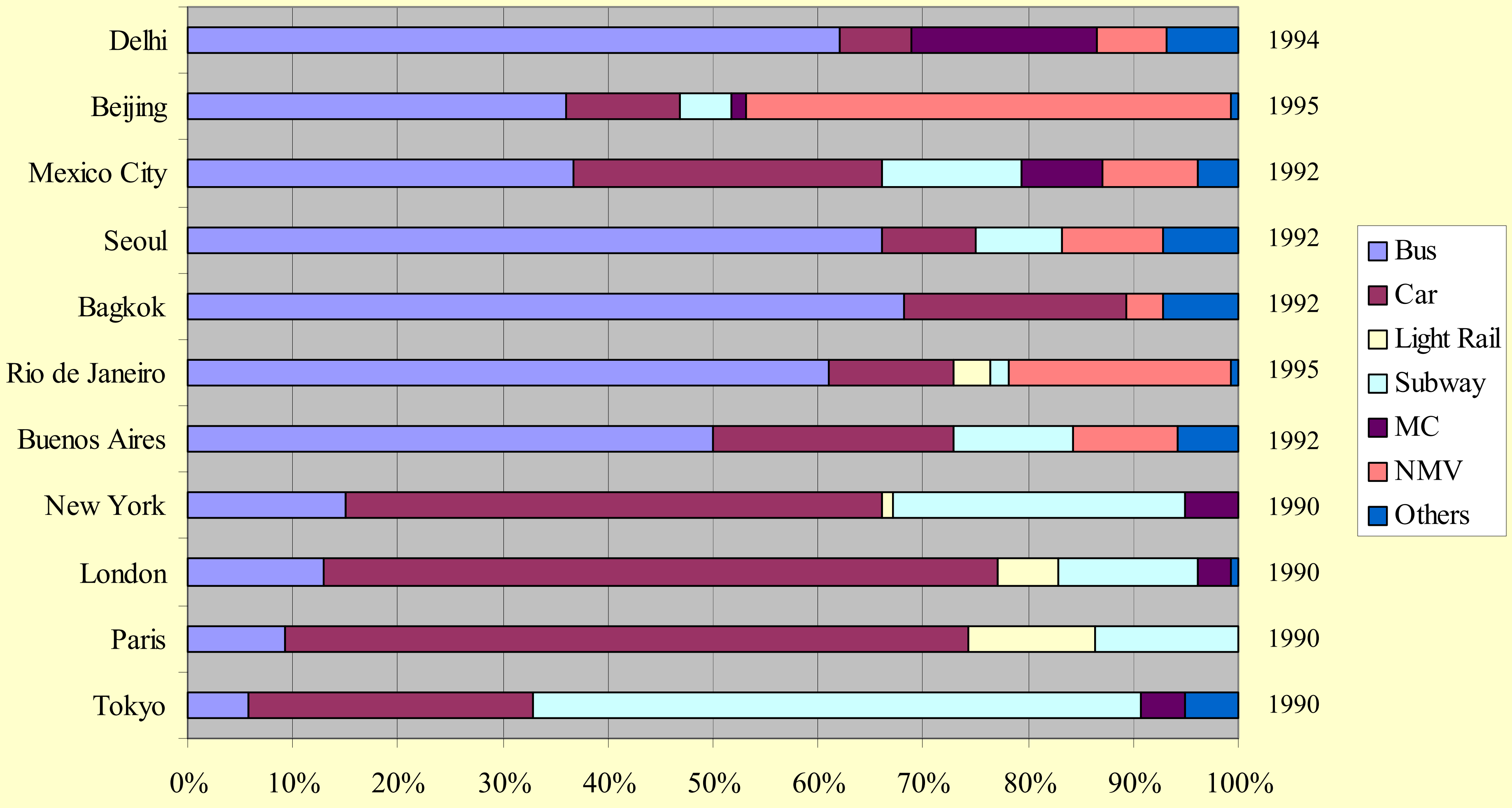
Presentation Outline

- Transportation system characteristics and air quality in Delhi
- Spreadsheet vehicular air pollution information system for Delhi
  - Effects of technological improvements and congestion
- An optimization model
  - Different cases, results, and implications

Delhi's Transportation System

- Inadequate traffic management
- Inefficient public transport system
- Increasing incomes and economic activities
- Mostly personal vehicles (cars and two wheelers) with largely single occupancies
- Growing motorization: increasing number of trips per person and average trip distances

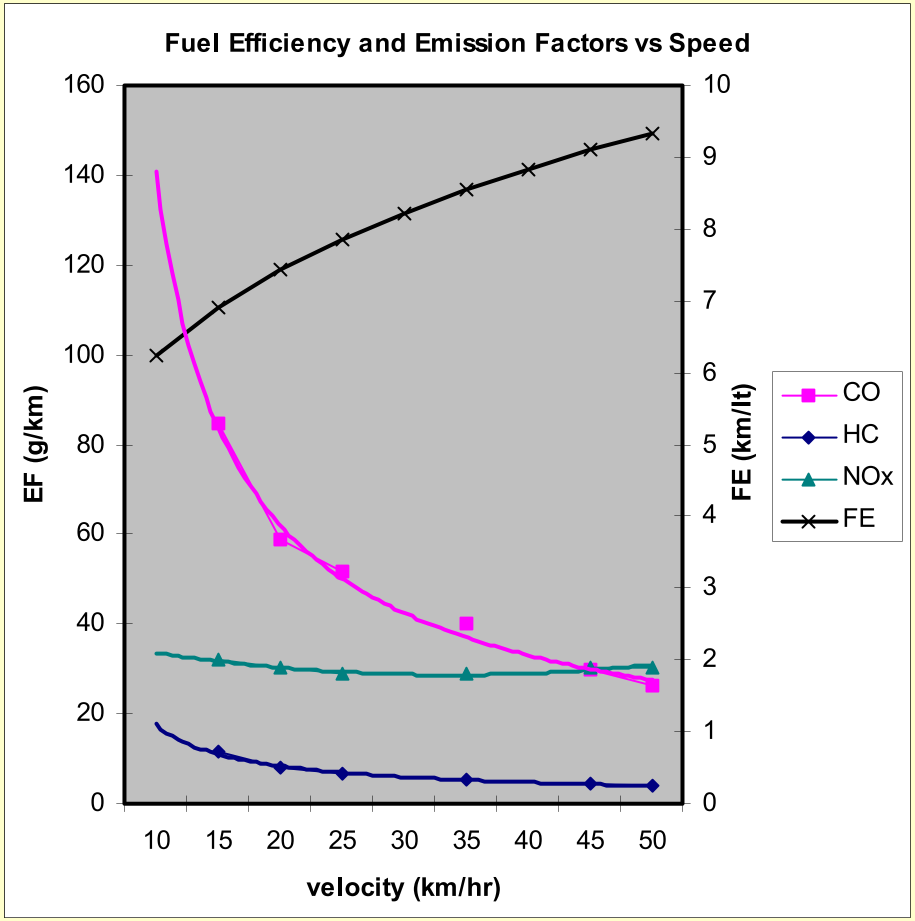
Comparison of Passenger Trip Mix Among Big Cities in the World



Delhi's Vehicle Fleet and Population

- Total # of motor vehicles per 1000 people in 1998 was 238 (expected 305/1000 in 2005).
- Largest vehicle population in the country: number of vehicles increased by 15 times in the past three decades (currently about 3 million vehicles for close to 14 million people)
- Highest road length in India: 1284km/100km2 area (26,379km of total length in 1998/99).
  - But no traffic segregation and lane discipline
  - ~10,000 accidents/yr: 10,000 injuries, 2,000 deaths
- Most congested city in India!
- Expected population for 2020: 22,000,000

Effect of Speed on Emission Factors and Fuel Efficiencies for Cars in Beijing



As fuel efficiencies decrease due to reduced speeds, emissions of other pollutants will also increase!

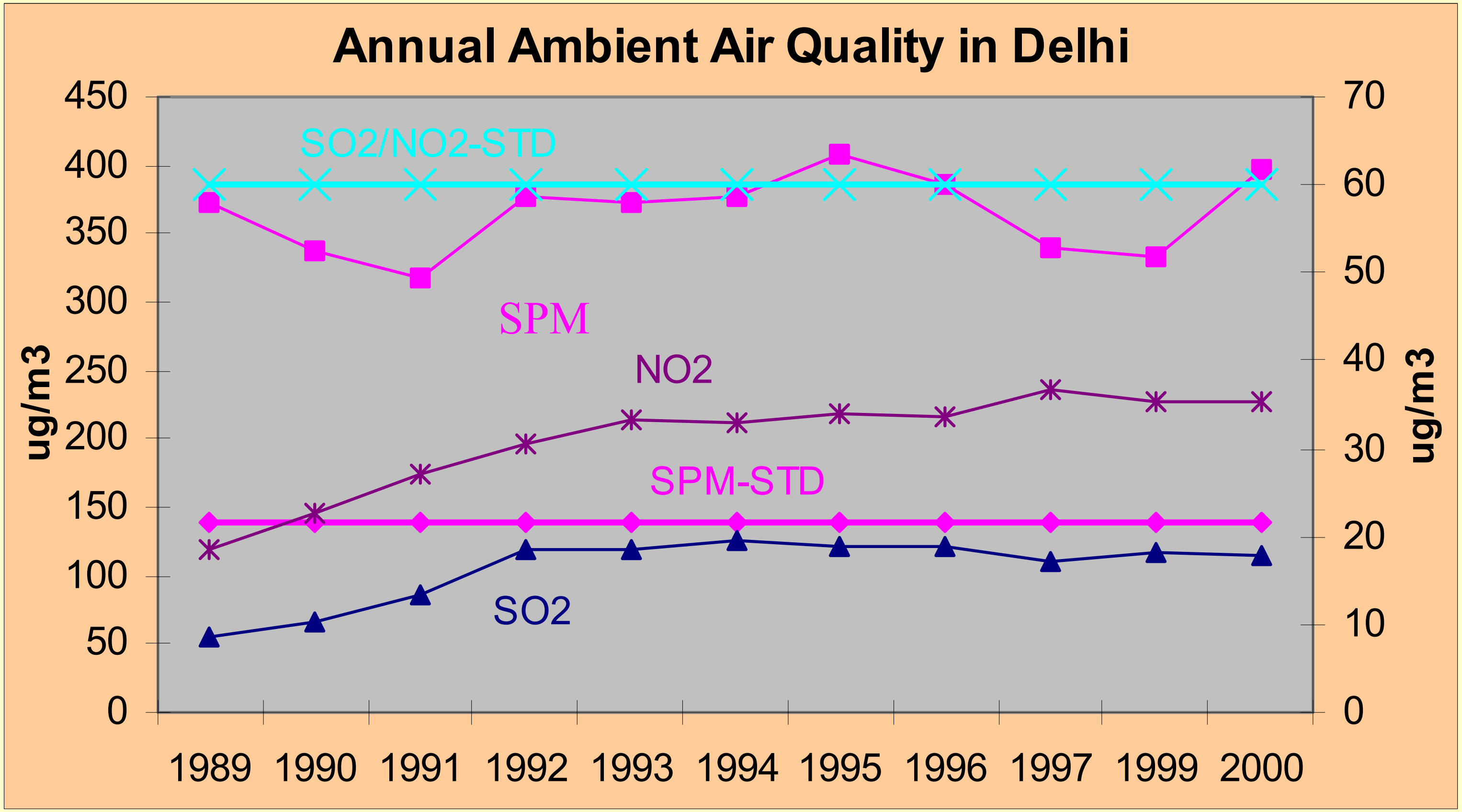
Even a small reduction in speeds from 20km/hr to 15km/hr increases fuel consumption by 25% (Stares and Liu, 1996).

Stop and go driving substantially increases vehicle emissions (very high emissions during accelerating and decelerating).

Increased congestion levels creating reduction in speeds will result in higher emissions and fuel consumption from transport activities!

Also more time will be spent in traffic!

Air Quality in Delhi



✶WHO named Delhi as the 4th most polluted city in the world in terms of suspended particulate matter.

✶Particulate pollution was reported to kill 1 person per hour in 1995 in Delhi (CSE, 1997).

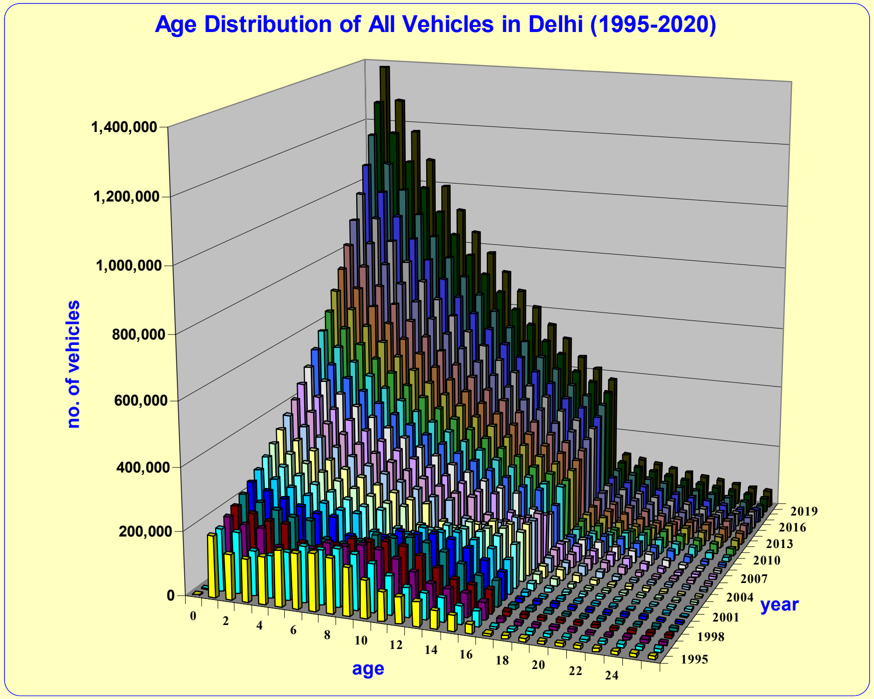
Transport Institutions & Data

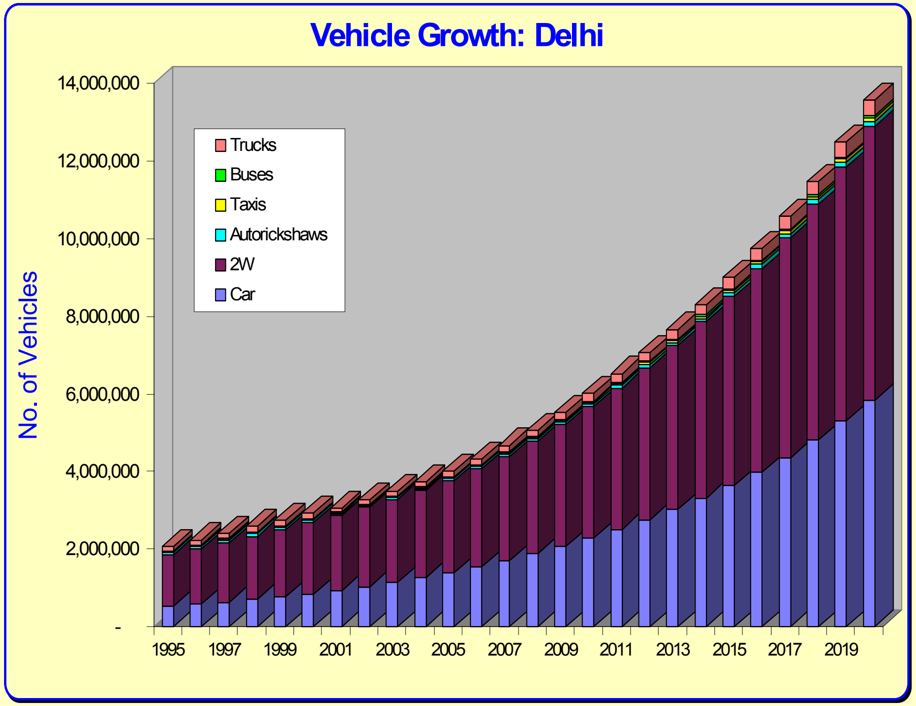
- Need for institutional and regulatory reform (multiple institutions are responsible for urban transport planning)
- Lack of coordination and poor enforcement
- Publicly available data very few and with questionable credibility
- Private organizations do not share their data

Spreadsheet Simulation

- Projects the number of vehicles, average vehicle fuel efficiencies (km/lt), average vehicle emission factors (g/km), age distribution of vehicles in each year, vehicle kilometers traveled per day, fuel consumption, and vehicular emissions when current growth rates are maintained into the future.
- Cases:
  - Case 1: Continuous technological advancement to meet fuel efficiency, emissions factors, and fuel quality improvements until 2020.
  - Case 2: Maintain 2000 technologies into the future.
  - Case 3: Case 1 with the effects of reduced speeds and congestion on fuel efficiencies and emissions factors.

Delhi's Vehicle Fleet

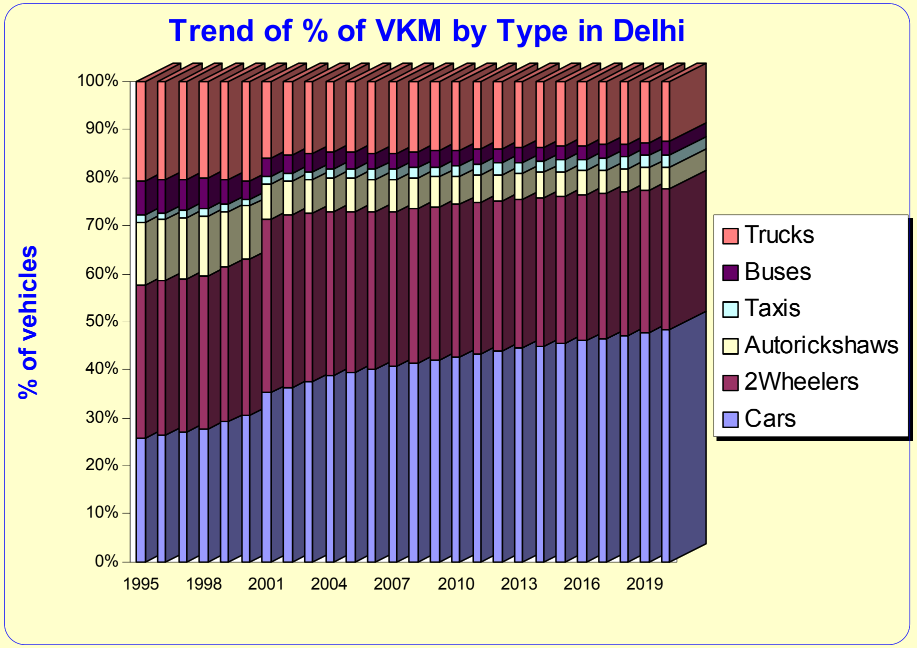


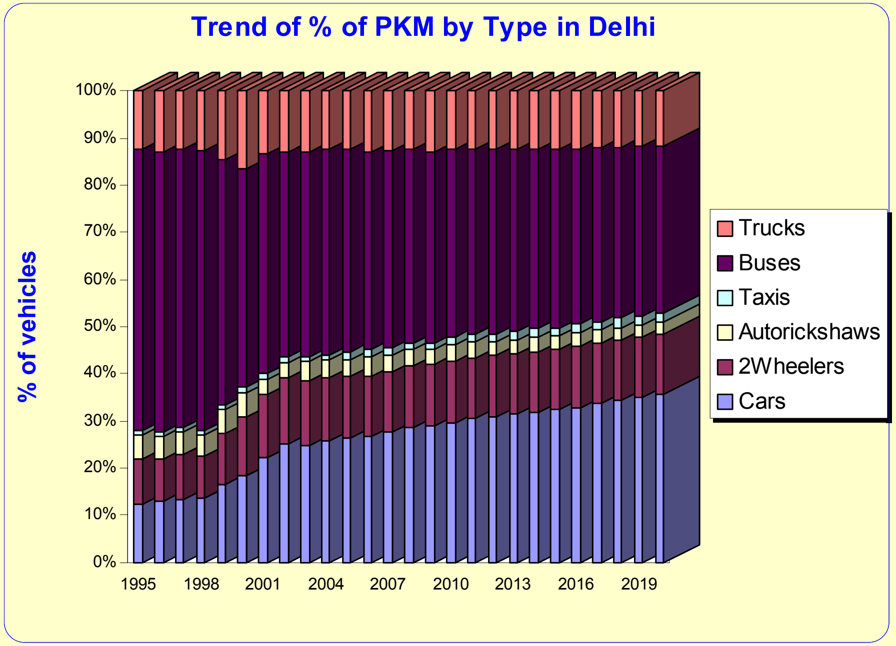


Percent of Vehicles Older Than 15 Years in Delhi's Vehicle Fleet

%	cars	2W	autorickshaws	taxis	buses	trucks	total
1995	12.30	0.00	7.35	28.05	21.97	20.11	4.91
2000	7.82	0.00	0.00	0.00	0.00	17.48	3.20
2001	7.90	0.00	0.00	0.00	0.00	0.00	2.43

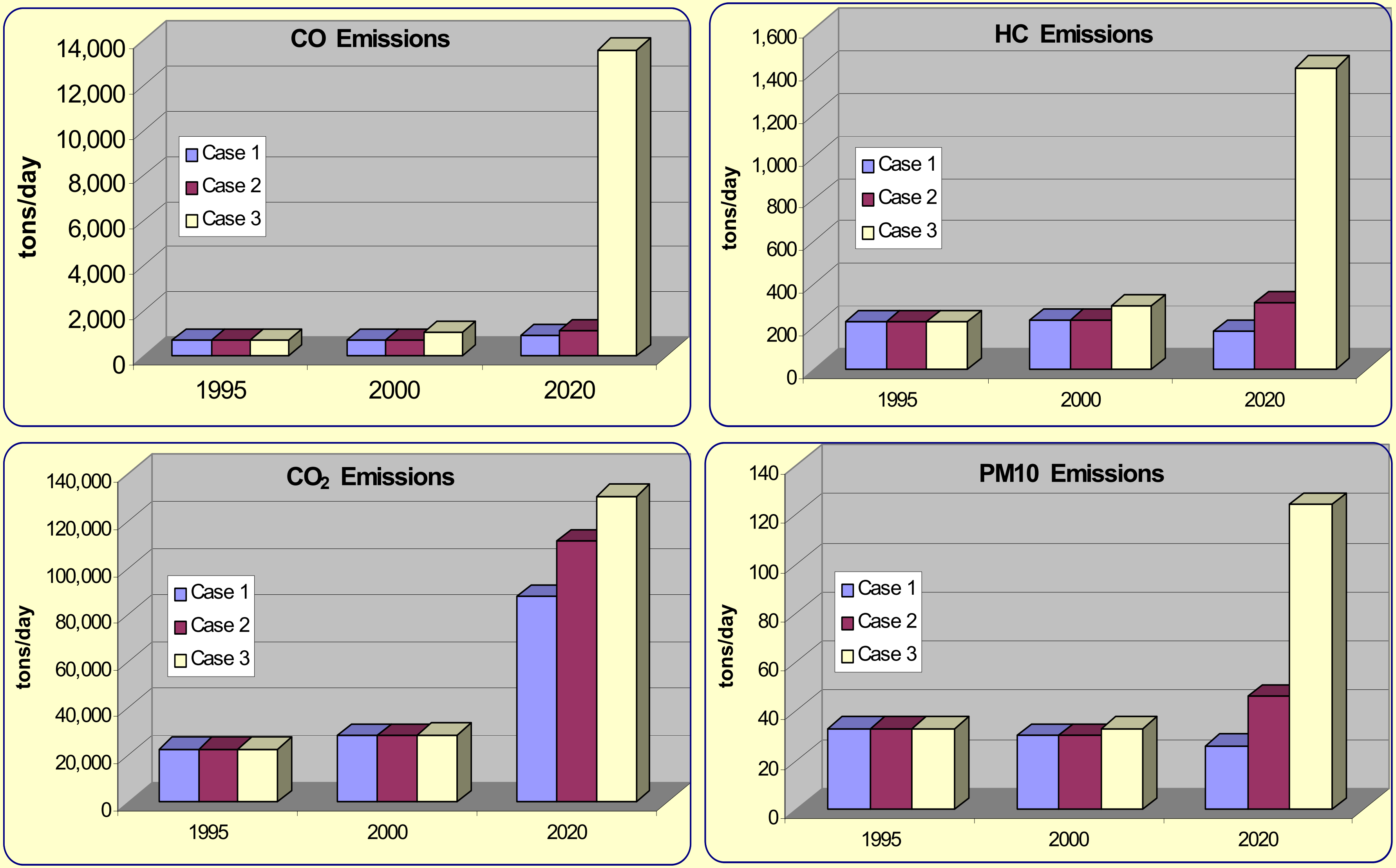
VKM & PKM by Mode



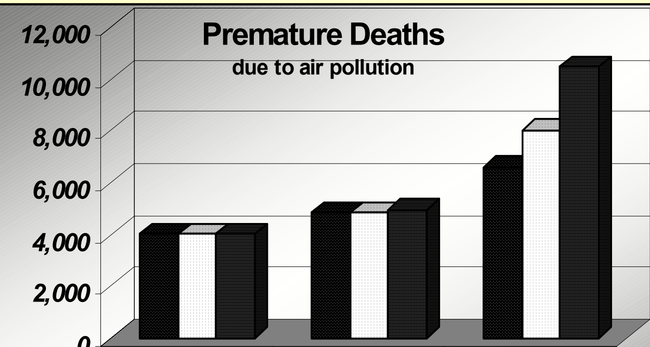


- Although cars and two wheelers make up close to 95% of total vehicles in 2020, they meet about 45% of the pkm demand.
- Buses will continue to meet most of the transport demand in Delhi (less than 0.5% of total fleet in 2020 still satisfying about 40% of the pkm demand).

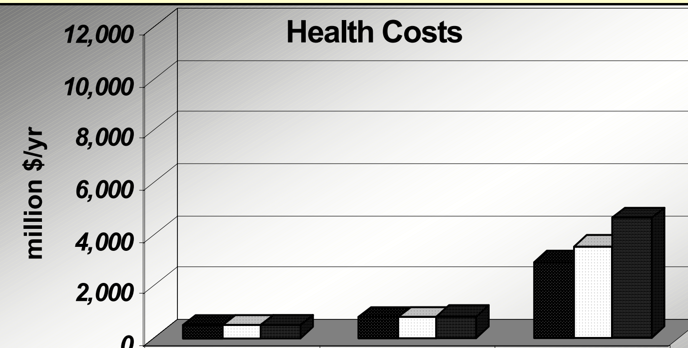
Emissions from the 3 Cases



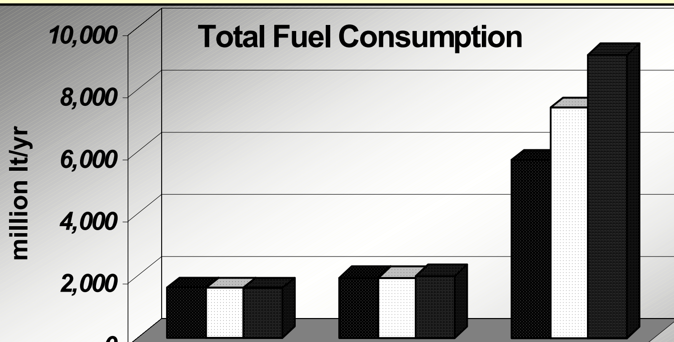
Value of Time, Fuel Costs, and Health Impacts of Vehicular Air Pollution



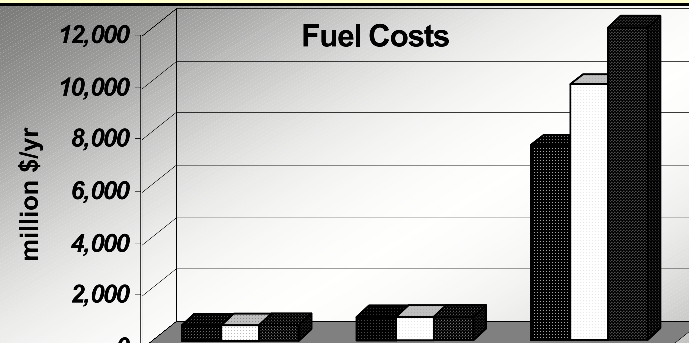
	1995	2000	2020
Case 1	4,027	4,827	6,614
Case 2	4,027	4,827	8,009
Case 3	4,027	4,963	10,463



	1995	2000	2020
Case 1	495.15	800.73	2,918.64
Case 2	495.15	800.73	3,532.15
Case 3	495.15	823.08	4,617.93



	1995	2000	2020
Case 1	1,602	1,949	5,726
Case 2	1,602	1,949	7,410
Case 3	1,602	2,008	9,123



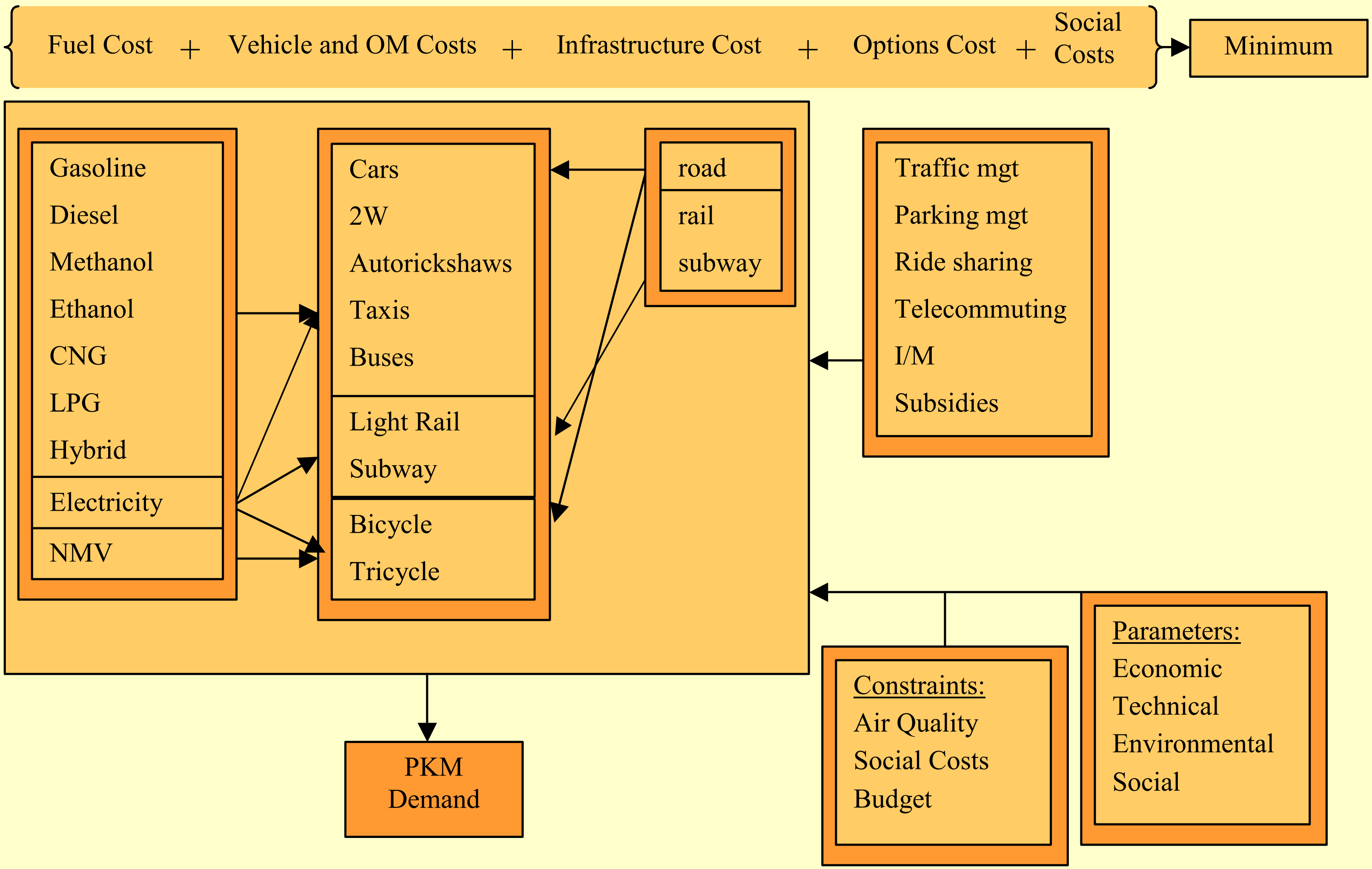
	1995	2000	2020
Case 1	586.7	882.67	7,452.50
Case 2	586.7	882.67	9,787.14
Case 3	586.7	909.89	12,029.16

Value of Time	1995	2000	2020
Case 3	162.79	391.04	16,536.75

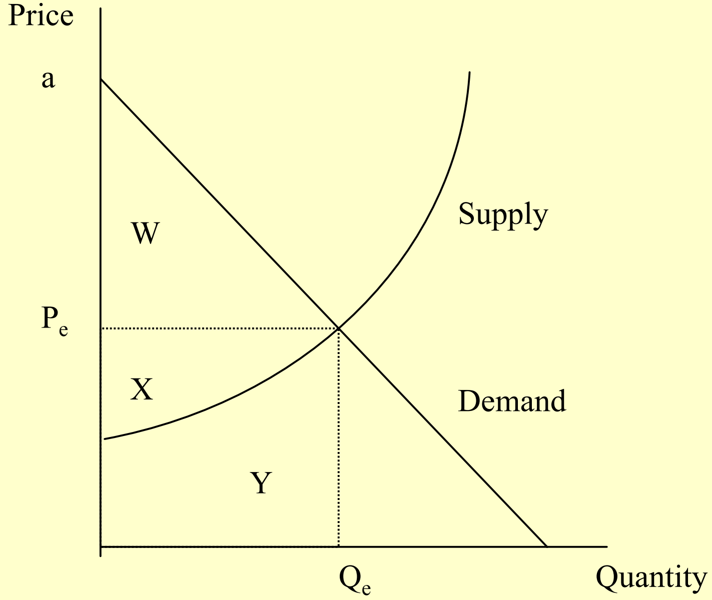
Conclusions & Summary of Simulation Model Results

- Projection of the vehicle fleet at current growth rates will result in more than 13 million vehicles, mostly cars and two wheelers, for a population of close to 22 million people by the year of 2020.
- Buses satisfy a very large amount of the transport demand despite the fact that their numbers are so small. So measures directed to facilitate their operation are a must.
- Even though the vehicle fleet becomes younger and cleaner due to lower retirement ages, strict fuel efficiencies and emissions standards, and fuel quality improvements, costs of externalities from this growing transportation system will increase by large amounts.
- Although technological improvements are necessary and they attain large reductions in health costs and fuel costs, the effects of traffic congestion and reduced speeds on emissions and fuel consumption from vehicles are even higher. Therefore, appropriate measures should be taken to reduce these adverse effects of reduced speeds and increase the efficiency of the transport system.

Optimization Model Structure



General Equilibrium Analysis of the Maximization of Producers' and Consumers' Surplus



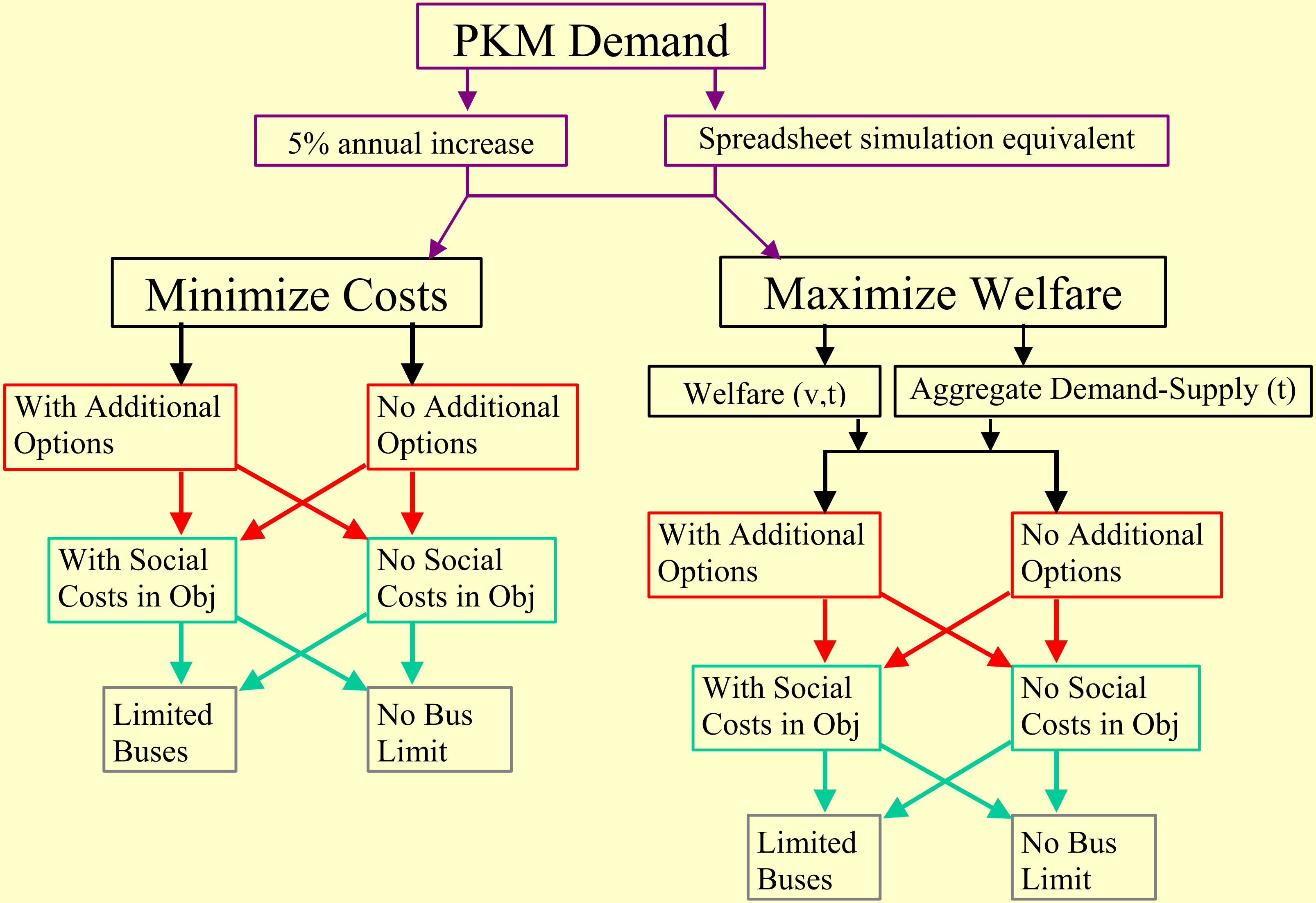
Price: cost/pkm (v,t)
Quantity: pkm (v,t)

Welfare = Area under the Demand Function
- Area under the Supply Function
= Consumers' surplus (W)
+ Producers' surplus (X)

Demand and Supply Relationships for Welfare Maximization

Optimization Model Cases

- ✶ Minimizing Total Costs of Transportation System
- ✶ Maximizing Welfare from Transportation

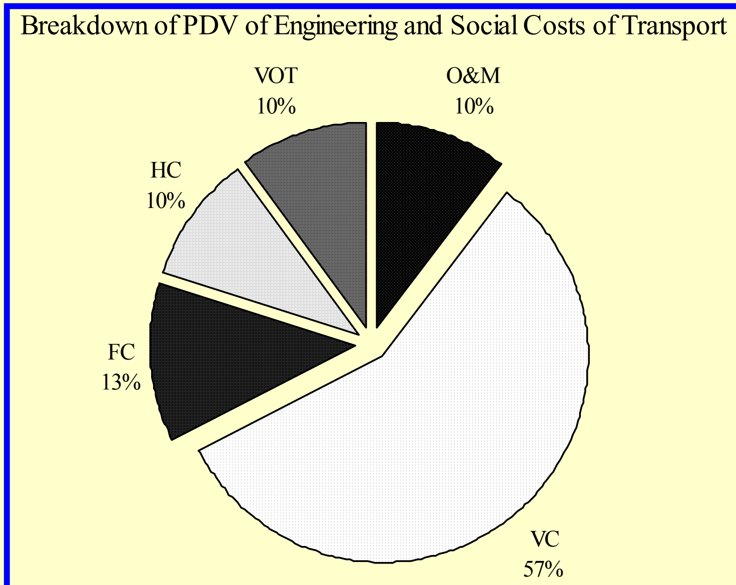


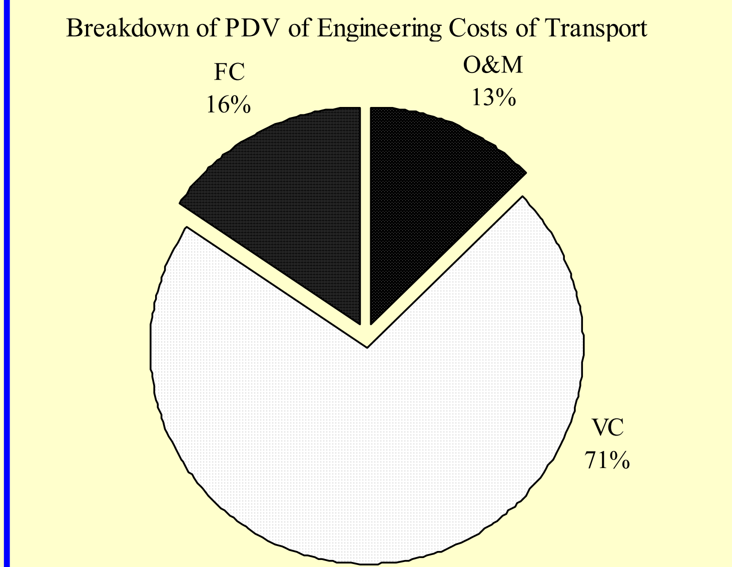
Cases Analyzed

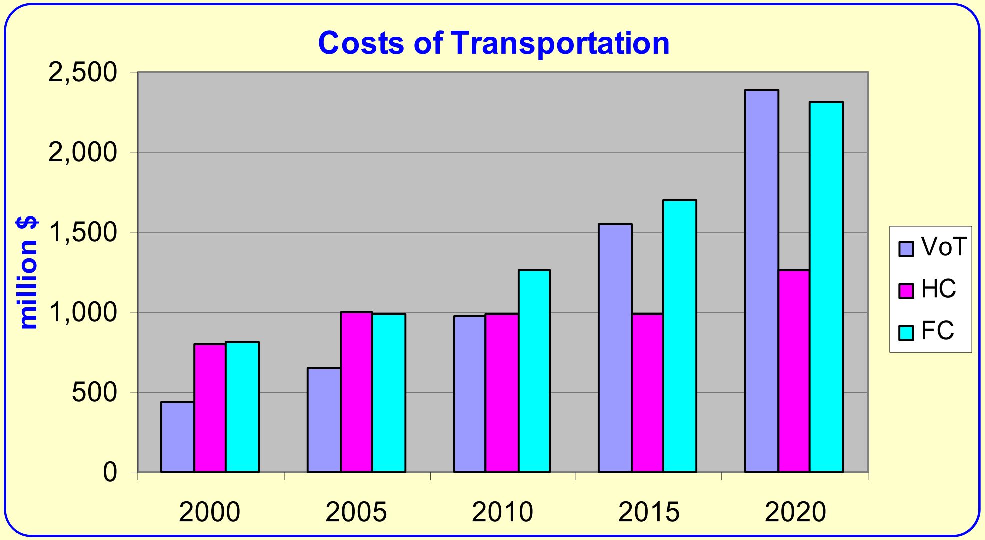
- **Case 1:** Minimizing total costs without social costs with only the first three control options for vehicle technologies, fuels, and rail infrastructure with SET 1 PKM demand
- **Case 2:** Case 1 with SET 2 PKM demand
- **Case 3:** Case 2 with social costs
- **Case 4:** Case 2 with all the traffic control options
- **Case 5:** Maximizing welfare without social costs with only the first three control options for vehicle technologies, fuels, and rail infrastructure with SET 2 PKM demand
- **Case 6:** Case 5 with an aggregate demand and supply curve for total motor vehicles
- **Case 7:** Case 1with limited number of buses (35,000)
- **Case 8:** Case 2 with limited number of buses (50,000)
- **Case 9:** Case 5 with limited number of buses (50,000)
- **Case 10:** The spreadsheet simulation

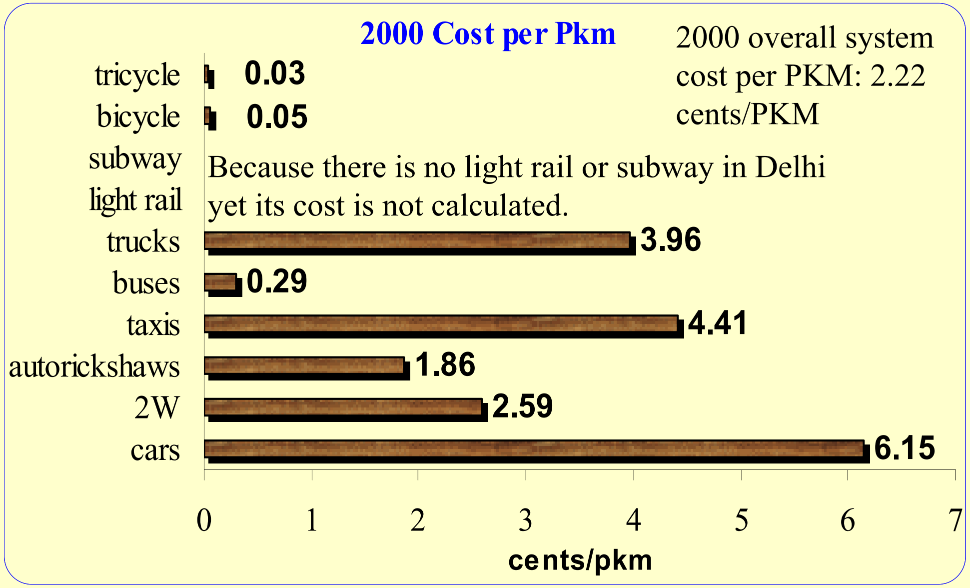
SET 1: 5% annual growth rate in travel demand over base year 2000.
SET 2: Spreadsheet simulation equivalent travel demands.

Transportation System Costs in Delhi for Case 1

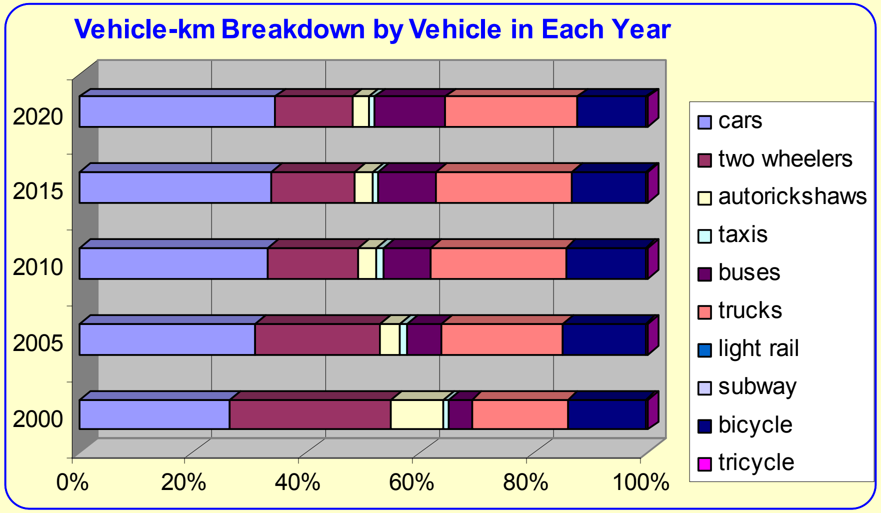


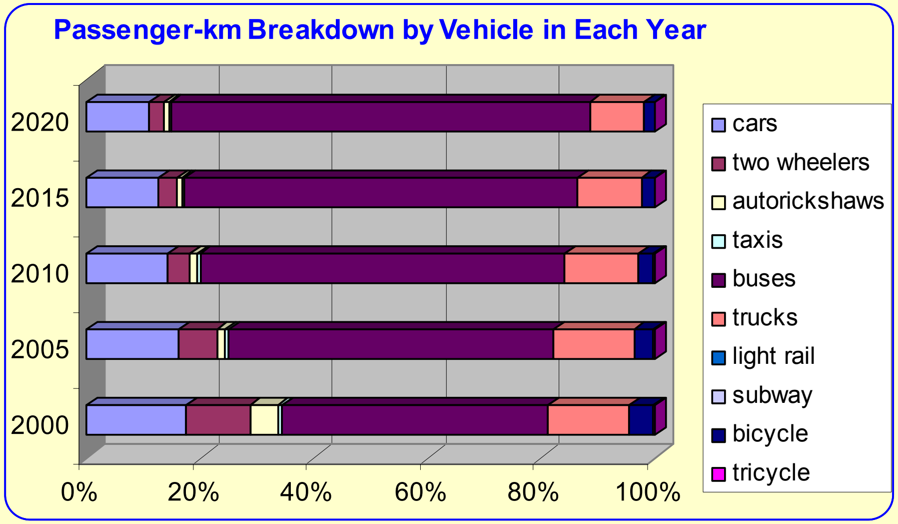




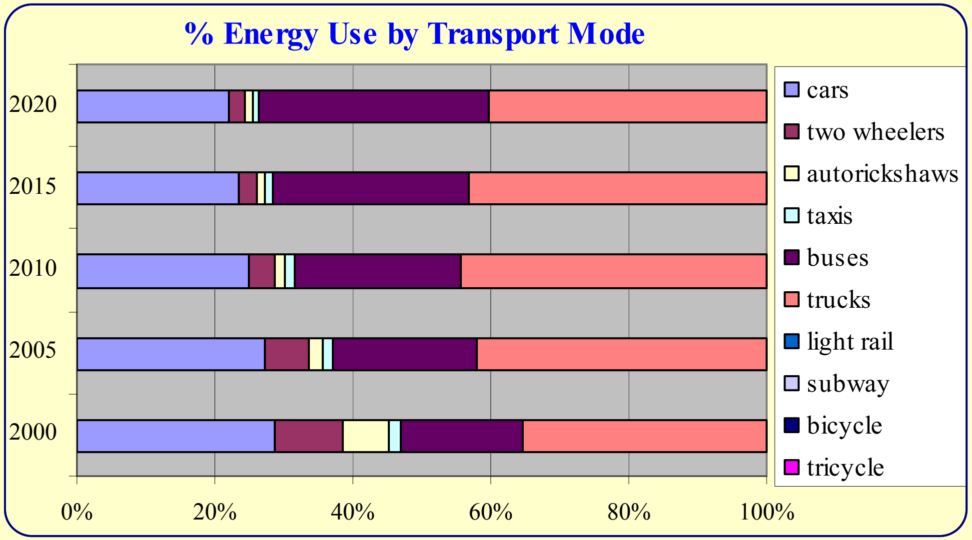


VKT, PKM, and Energy Use Breakdown by Travel Mode for Case 1

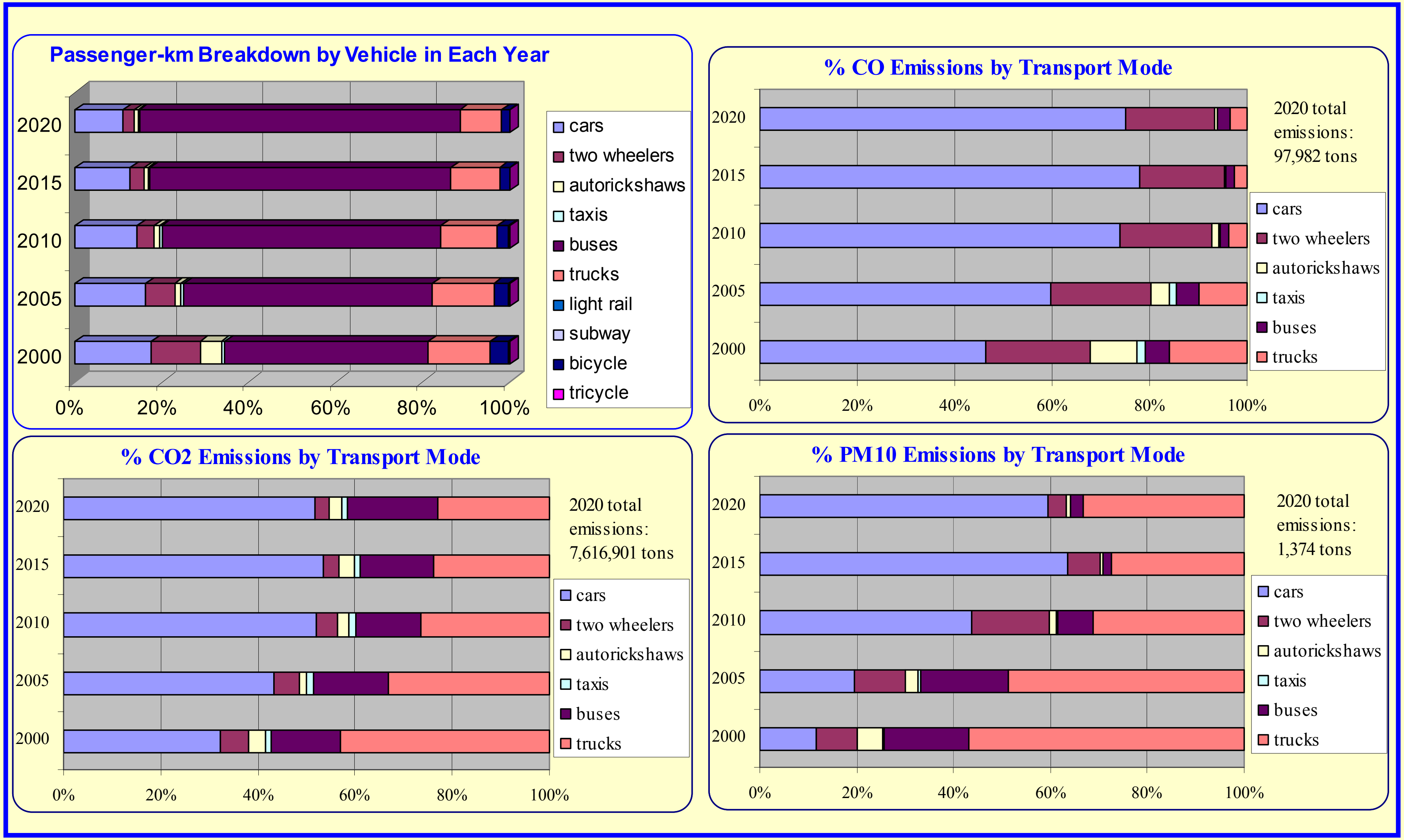




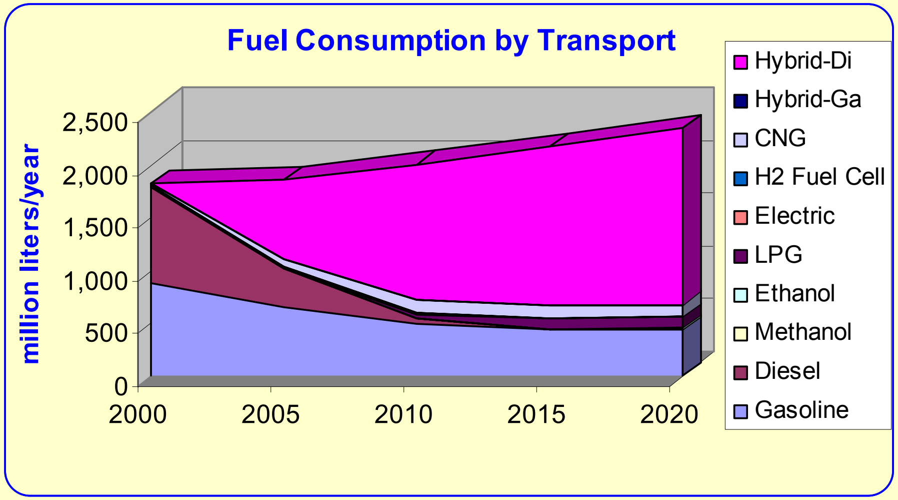
no. of vehicles	2020		2020
cars	1,267,537	subway	0
two wheelers	1,000,000	light rail	0
autorickshaws	25,000	bicycle	2,200,000
taxis	11,600	tricycle	60,000
buses	71,210		
trucks	244,435		
% of motor vehicles		2020	
cars		48.38%	
two wheelers		38.17%	
autorickshaws		95.00%	
taxis		44.00%	
buses		2.72%	
trucks		9.33%	

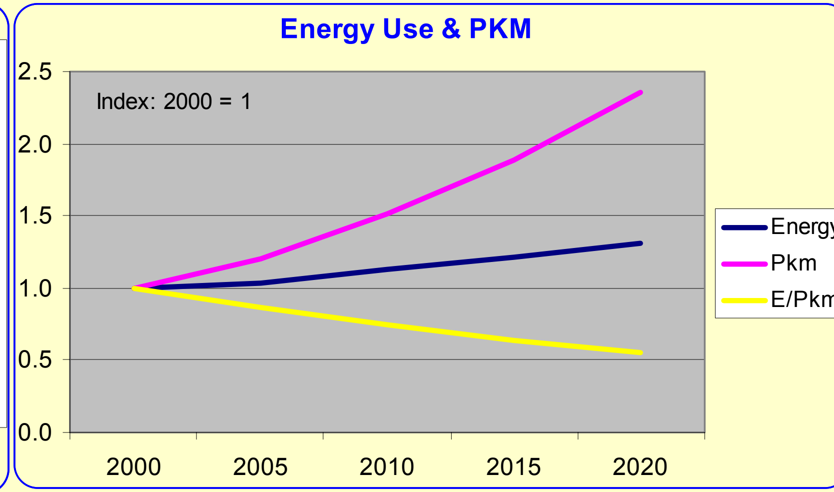


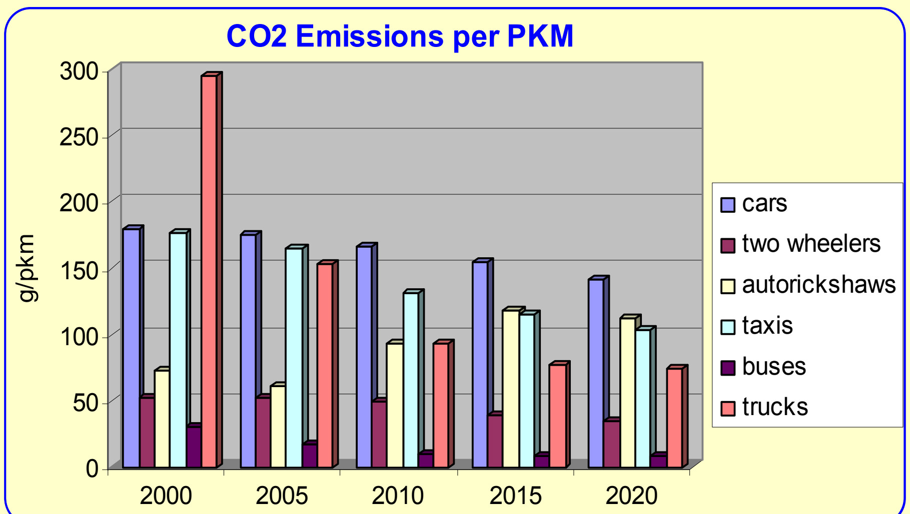
PKM, CO_2, CO, and PM10 Emissions breakdown by travel mode for Case 1

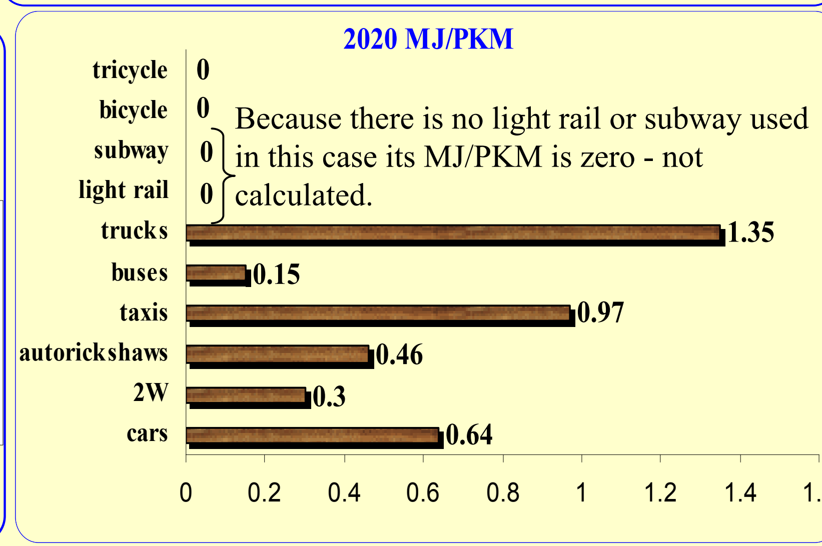


Fuel consumption by mode & energy use and CO_2 emissions per PKM for Case 1

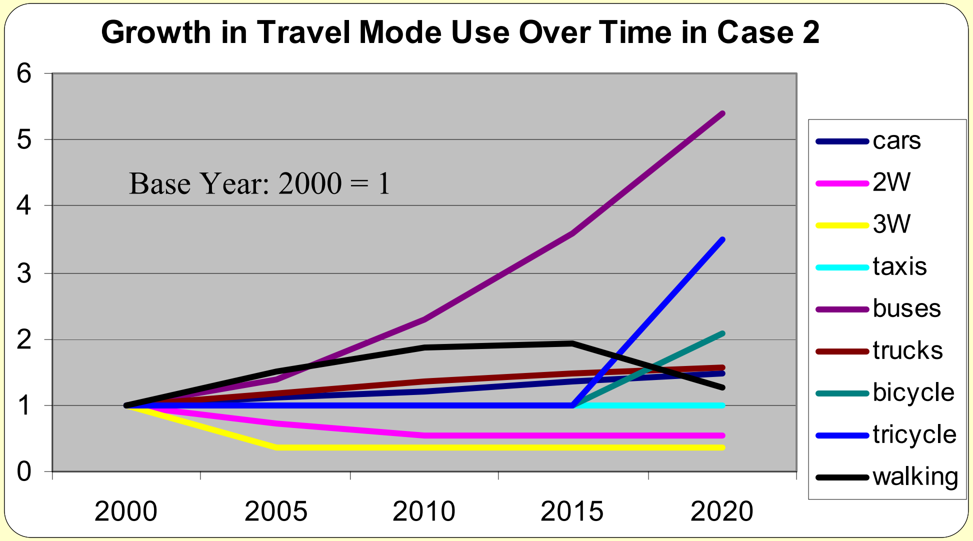






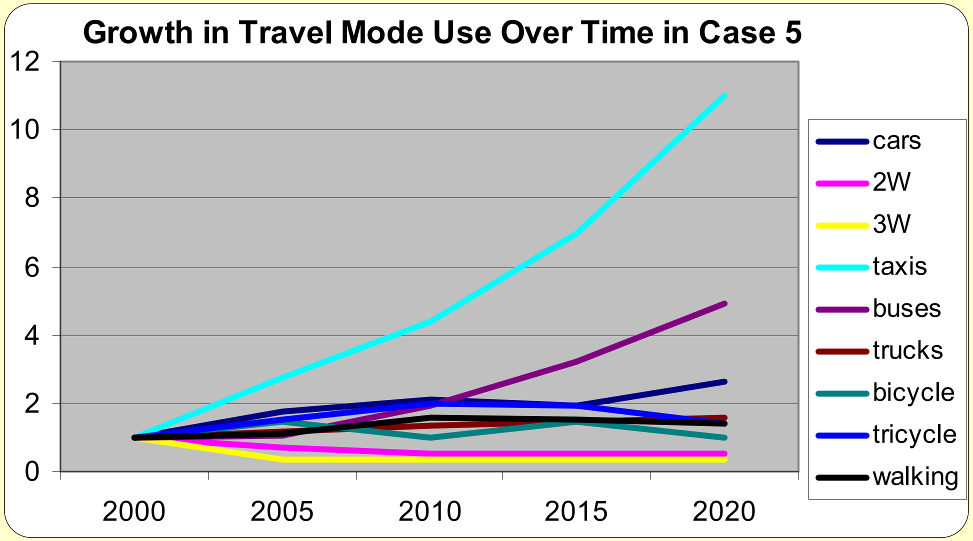


Minimizing Costs vs Maximizing Welfare: Vehicle Fleet Breakdown (# of vehicles)



Minimize Costs

Case 2	2020
cars	1,267,537
2W	1,000,000
3W	25,000
taxis	11,600
buses	103,635
trucks	244,435
subway	-
light rail	-
bicycle	4,597,534
tricycle	210,000



Maximize Welfare

Case 5	2020
cars	2,242,478
2W	1,000,000
3W	25,000
taxis	128,000
buses	94,470
trucks	244,435
subway	-
light rail	-
bicycle	2,200,000
tricycle	82,812

Vehicle Fleet Distribution by Type in 2020 in Delhi for the 10 Cases

2020	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7	Case 8	Case 9	Case 10
total motor vehicles	2,619,781	2,652,206	2,652,206	2,641,187	3,734,383	2,648,425	6,066,004	12,186,843	8,165,821	13,556,004
cars	1,267,537	1,267,537	1,267,537	1,267,537	2,242,478	1,267,537	1,267,537	1,286,409	6,580,560	5,831,141
two wheelers	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000	1,000,000	4,229,432	10,200,000	1,000,000	7,044,943
autorickshaws	25,000	25,000	25,000	25,000	25,000	25,000	278,000	278,000	25,000	121,510
taxis	11,600	11,600	11,600	11,600	128,000	11,600	11,600	128,000	265,826	98,284
buses	71,210	103,635	103,635	92,615	94,470	99,853	35,000	50,000	50,000	53,569
trucks	244,435	244,435	244,435	244,435	244,435	244,435	244,435	244,435	244,435	406,557
subway	-	-	-	-	-	78	-	175	89	
light rail	-	-	101	-	-	289	667	667	108	
bicycle	2,200,000	4,597,534	2,200,000	2,200,000	2,200,000	2,200,000	13,000,000	13,000,000	2,200,000	
tricycle	60,000	210,000	210,000	166,493	82,812	60,000	210,000	210,000	702,382	

Case 1: Min Cost SET 1 PKM

Case 2: Min Cost SET 2 PKM

Case 3: Case 2 + Social Costs

Case 4: Case 2 + All Options

Case 5: Max Welfare SET 2 PKM

Case 6: Case 5 with aggregate D-S

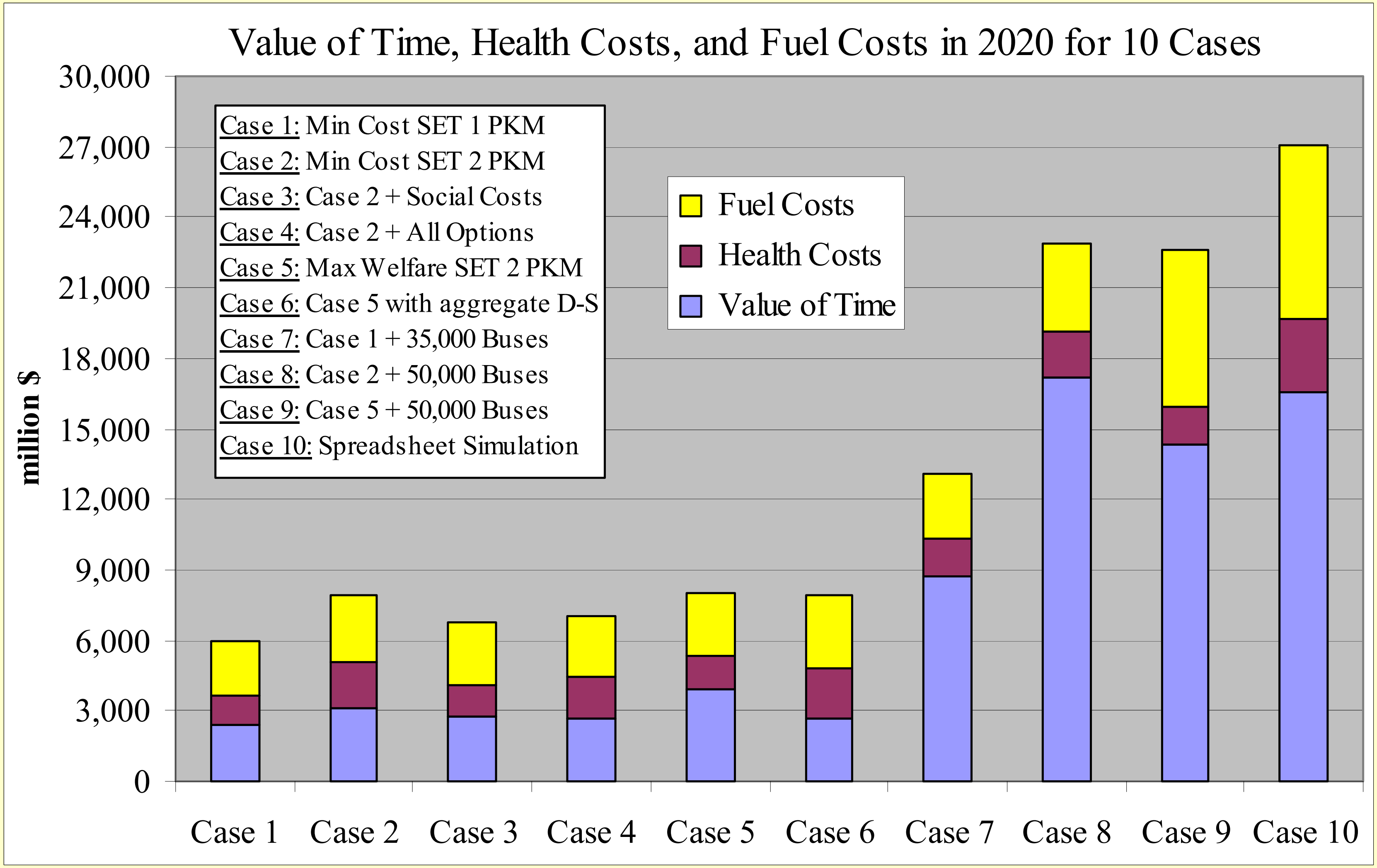
Case 7: Case 1 + 35,000 Buses

Case 8: Case 2 + 50,000 Buses

Case 9: Case 5 + 50,000 Buses

Case 10: Spreadsheet Simulation

SET 1: 5% annual growth rate in travel demand over base year 2000.
SET 2: Spreadsheet simulation equivalent travel demands.



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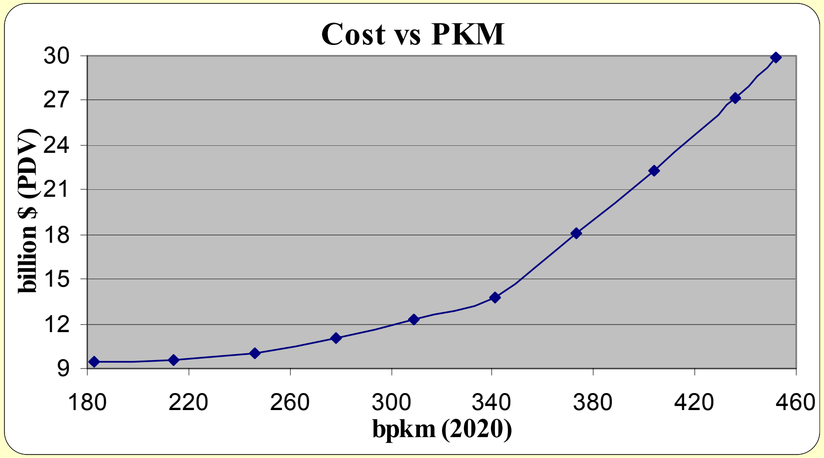
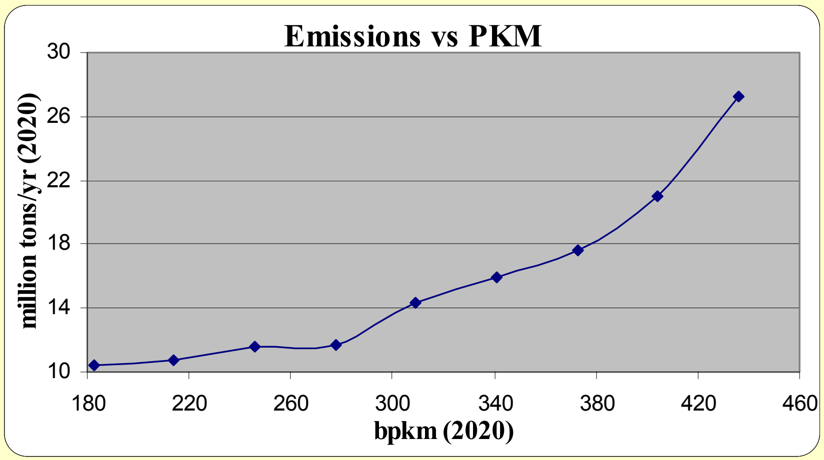
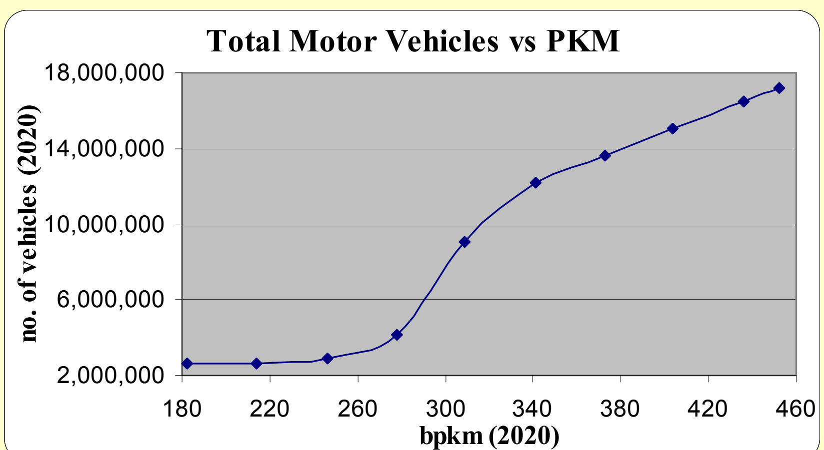


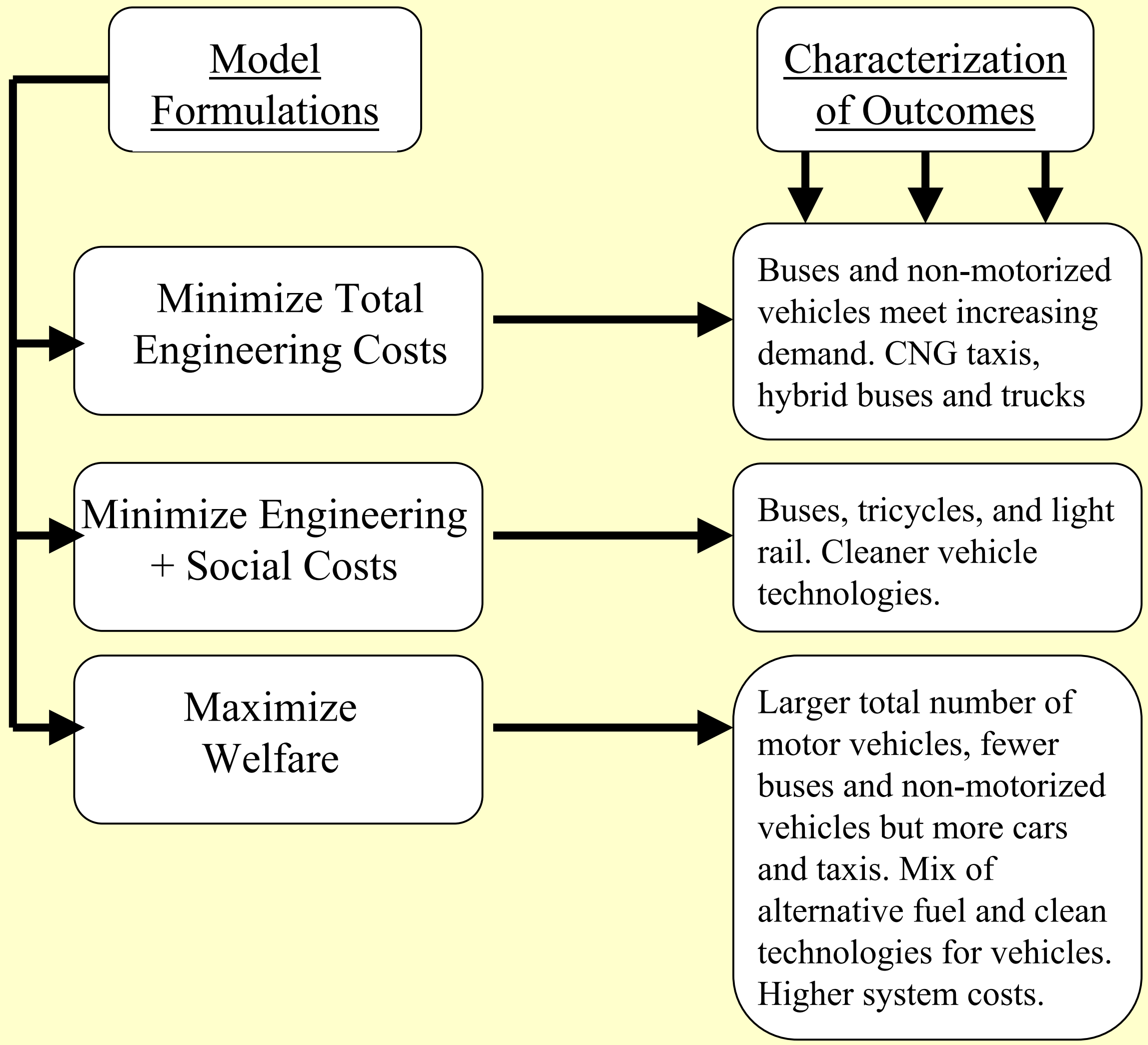




Tradeoff Curves for PKM vs Costs, Emissions, and Number of Vehicles in Case 8:

It is very important to forecast a fairly exact travel demand for the future, but as long as the demand is below the elbow point of these tradeoff curves, it would be possible to plan for a rather cost-effective transport system with the suggested model solutions.

Main Model Formulations and Their General Outcomes



Conclusions & Summary of Optimization Model Results

- Less repetitive work involved in optimization – an integrated way of looking at an extensive list of control options.

- Cleaner vehicles need to be adopted due to emissions reduction requirements included in the optimization model. Competitive vehicle technologies in the cost minimizing cases turn out to be: CNG taxis, hybrid buses and trucks, electric, LPG, and CNG autorickshaws, gasoline and CNG cars, and ethanol, LPG, and CNG two wheelers. A mixture of alternative fuels and clean vehicle technologies are chosen in welfare maximizing cases still maintaining widely the choice of CNG for taxis and hybrid for buses and trucks.

- The total # of motor vehicles are higher in welfare maximizing cases compared to their parallel cost minimizing cases. In general more cars and taxis and fewer buses are used in these cases.

- Addition of social costs in the objective function results in some cases with the use of more light rail, less bicycles, and lower VoT, and in almost all the cases in the use of cleaner vehicle technologies and consequently lower health costs.

Conclusions & Summary of Optimization Model Results

- Addition of all the control options in the optimization results in less total # of motor vehicles, higher speeds, and lower value of time and health costs to achieve a social optimum.

- Most cost-effective mode of transport chosen by the optimization model is Buses! Buses are Delhi's future!
  - When buses are limited a lot more vehicles in all the other modes are required to meet the transport demand. As a result social costs are higher.
  - More two wheelers, autorickshaws, bicycles, subway, and light rail are used in cost minimizing cases. More cars, taxis, and tricycles meet the left over demand in welfare maximizing cases.

- A very well planned public transport system, with dedicated bus lanes and bus priorities, is essential for developing a sustainable transportation system in Delhi!

The End

Thank You!