Hybrid Vehicle Emissions Analysis

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February 27, 2002

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The object of this analysis of the hybrid vehicle is to determine what ecological impact the hybrid vehicle will have when being driven in significant numbers. Current pollution by automobiles in the city of Worcester, Massachusetts, amounts to over 6000 tons each year. The side effects of this much pollution include smog filed skies, and various health hazards, from increased asthma to cancer rates. The ability to reduce this vast amount of pollution by any means possible is valuable, and the hybrid vehicle may be one solution.

The hybrid vehicle designed to reduced emissions or increase fuel efficiency is in either case much cleaner than most other automobiles. The organization in charge of emissions regulation in the United States of America is the Environmental Protection Agency, EPA. The EPA has instituted a strict set of emissions restrictions upon automobiles and ranks each vehicle sold in the United States in an emissions cutoff category. This category ranking system helps inform the public as to which vehicles available to them are heavy polluters and which are the cleanest. The cleanest category in the EPA's ranking system is called SULEV, short for Super Ultra Low Emissions Vehicle; currently there is only one type of vehicle in this category, the hybrid.

When conventional internal combustion vehicles are replaced by gas electric hybrids the reduction in emissions is nothing short of amazing. In fact an internal combustion engine vehicle pollutes 7 times more than a Hybrid vehicle. Hybrid vehicles show the greatest impact upon the population of "older" vehicles, model year 1996 or older, due to the absence of such strict EPA restrictions in many of those years. If all "older" vehicles were to be replaced by hybrids the total pollution per year in Worcester would drop from 6258 tons to merely 2124 tons. To replace only the "new", model year 1996 and newer, by hybrids we would reduce the pollution by only 1600 tons. To totally replace all of the vehicles on the road by hybrids would reduce the pollution to only 16 percent of its former amount, only 1000 tons of airborne pollution.

The correct solution at this point is most likely none of these scenarios. As the EPA has done in the past, a "phasing in" of new restrictions would prove the best policy, over the next 5 to 10 years automobile manufacturers should be required to produce an incrementally increasing number of SULEV vehicles, slowly phasing in this new technology. "Old" vehicles should be replaced as soon as possible, and newer vehicles would obviously be of a lesser priority but are still important in the cleaning process.

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Introduction:

Mankind has been living with the automobile for nearly a century; in this time we have seen drastic changes in the uses of and the requirements for this form of transportation. Therefore, it is not surprising that we see such a large area of technological development focused upon the automobile and its improvement. Today the automobile in all its forms, passenger car, large commercial and industrial vehicles alike, represents the most used and versatile means of moving goods and persons from one location to another.

The invention that made automobiles practical and worthwhile was undoubtedly the internal-combustion engine. Powered by the internal-combustion engine, the automobile is able to travel independent of external energy sources, requiring only a small amount of fuel or inconvenience when compared to steam or electric vehicles. The abundance of petroleum based fuels also allows the driver to travel nearly anywhere without needing to worry about fuel sources. This ease of use coupled with versatility is the main reason the number of modern automobiles ranks in the hundreds of millions across the globe.

These vast numbers of automobiles also present issues which in many cases cause controversy. Petroleum is a nonrenewable source of fuel, and every day Oil Company's drill the oil becomes more expensive to extract and takes a larger ecological toll. The cars themselves have a rather significant ecological impact, an impact which living organisms on this planet are forced to deal with every day.

The internal-combustion engine that has made life easier in so many aspects is also hurting us in a rather startling manner. Large commercial and industrial centers

often find themselves shrouded in a haze of smog, the noxious combination of smoke and fog. Smog is merely the combination of combustion byproducts and the atmosphere, creating a thick choking airborne pollution.

On the other hand, the electric car, which was never realized as a practical vehicle, has no emissions of any sort. It makes sense that through continued technological development, which is embodied in the automobile, we see a hybridization of the gasoline-powered internal-combustion engine and the battery-powered electrical systems. The hybridization of petroleum-electric automobiles originated in 1897 with the development of the first hybrid vehicle. The first hybrid vehicle although not much by today's standards was an engineering attempt at capturing the energy of fossil fuels and the drive train efficiency of electric motors.[i] The goal of the makers of these hybrid cars is to produce a vehicle as versatile and convenient as the gasoline engine with the efficiency and cleanliness of the electric motor. There are precious few of these hybrid vehicles available to the average consumer, the most note-worthy two being the Honda Insight and Toyota Prius, and soon to come Ford Escape.

This study aims to discover whether the introduction of the hybrid vehicle into the automobile population will have any significant impact upon the pollution generated by internal combustion vehicles each year. Whether for good or bad, this study should open the way for more exploration into the topic of practical alternative vehicle design and the impact such designs can have on our surroundings.

Literature Review:

The internal-combustion engine produces three chemical categories that we are most concerned with: Hydrocarbons, Nitrous Oxides, and Carbon Oxides. The Hydrocarbon category consists mainly of volatile organic compounds; hydrocarbons include the extremely hazardous formaldehyde and benzene, known carcinogens.[ii] Carbon Oxides can either be in the form of carbon dioxide, or carbon monoxide, if one is exposed to a large amount of the later it can have fatal consequences. The danger presented by these substances and their proximity to humans was one of the driving forces for the creation of the Clean Air Act and major action being taken by the EPA.

The current standards decreed by the Environmental Protection Agency for automobiles are designed to decrease the presence of toxins in our air. In the early 1950's a California study discovered a correlation between the fumes produced by automobiles and the hazy fog that was forming over Los Angeles.[iii] The presence of the smog is not surprising when one realizes that in the early fifties the average vehicle was producing approximately 52 times the current emissions for hydrocarbons, 25 times for carbon monoxides, and 9 times for nitrogen oxides.[iv] The current federal standards, listed in Table 1, represent the limit that can be reasonably imposed at our current level of technology, without impeding our economy's growth.

Table 1 - Emissions Standards

Pollutant	Current Federal Standard – Tier 1 *(grams/mile)*
HC[1]	0.31
CO[2]	4.2
NO_x[3]	0.6

Vehicles are divided into categories depending upon their fuel efficiency, size and weight; the standards given here are for Tier 1, the most heavily polluting Tier (a complete list of standards can be found in Appendix I under Table 6). When vehicles are emissions tested as a requirement for state inspection they must be below these cutoffs, which are 0.31, 4.2, and 0.6 grams per mile non-methane hydrocarbons, carbon monoxide, and nitrogen oxides respectively.[v] Vehicles which fit in other Tiers will have tighter restrictions upon their emissions, nonetheless even the heavy polluting vehicles are much cleaner today than they were fifty years ago. New vehicles are designed with these cutoffs in mind; these vehicles usually fall significantly lower than the cutoffs, allowing some leeway for deterioration caused by natural vehicle aging.

The small car or compact/subcompact car, a vehicle that makes up twenty three percent of the vehicles currently on the road, is one of the most popular vehicle sizes. The small car is the cleanest form of dual axle transportation available to the consumer at this point. The average compact/subcompact car travels twice the number of miles on the same gallon of gas as the ever-popular sport utility vehicle.

The Prius and Insight, compact and subcompact cars respectively, have the lowest emissions in their classes, ranking in Super, or Super Ultra, Low Emissions Vehicle, and

[1] HC : Hydrocarbons.
[2] CO : Carbon Monoxide.
[3] NO_x : Nitrous Oxides.

having the best miles per gallon for their classes.[vi] Vehicles that qualify for the SULEV category must meet very stringent guidelines, regulating the number of grams of Hydrocarbons and Nitrous Oxides released for each mile traveled. The qualification for this category is roughly the production of one pound or less of smog forming pollution for every 15,000 miles.[vii] The vehicles that are awarded the SULEV status show an amazing reduction in tailpipe emissions compared to other categories of vehicles. Table 2 shows the reduction in emissions when one compares a SULEV vehicle to a Tier 1 vehicle.

Table 2 - A Comparison of Emissions Standards

Pollutant	Clean Car Campaign – SULEV Standard *(grams/mile)*	Current Federal Standard – Tier 1 *(grams/mile)*	Reduction *(percent)*
HC	0.01	0.31	97%
CO	1.0	4.2	76%
NO_x	0.02	0.6	97%

To examine the problem of air pollution and the effect a hybrid vehicle could have on the current and future levels, the target city of Worcester, Massachusetts has been chosen. This city, with its instantaneous population of over two hundred and fifty thousand, has large industrial and commercial districts.[viii] Sampling a large city such as this one helps this study take into consideration the presence of commuting traffic, with large volumes of residents moving to and from work, and pleasure. The movement of large volumes of people in a relatively small area will create the most pollution due to the increased travel times between destinations, and the highly increased chance of stop and go driving, which forms the most pollution. In fact for this large Massachusetts city there are .79 vehicles for every person, meaning three out of four people have their own cars.[ix]

In this city where very little if any of the population uses public transportation this means a large volume of tailpipe emissions each and every day. In fact the Massachusetts Department of Environmental Protection and the Massachusetts Registry of Motor Vehicles claims automobiles cause forty percent of the airborne pollution in their state.[x]

The key to the future of the hybrid vehicle is to expand the consumer's options. Currently only the Toyota Prius and the Honda Insight are being mass-produced for consumers. With only two models available and a higher initial price than comparable models there is only a very small demand for these vehicles among consumers. Fortunately, nearly all vehicle companies have been working on their own hybrid vehicle projects.

The Ford Motor Company will be releasing their reinvented Ford Escape hybrid vehicle in the year 2003.[xi] This will be the first gas–electric Sport Utility Vehicle available to the consumer, a critical move for the hybrid industry due to the popularity of the SUV market at this point. With emissions low enough to fit the SULEV standard Ford hopes their new SUV will open up the market, offering consumers the choice of a larger more secure clean vehicle.[xii]

Toyota also has very recently released the Estima Hybrid, unfortunately available only in Japan at this point. The Estima, although not as clean as the Prius, is rated as a Low Emissions Vehicle. "It is the world's first hybrid-powered 4x4 monospace vehicle (Minivan)."[xiii] Seating up to 7 people the Estima is the first hybrid four-wheel drive vehicle, another step in a clean direction.[xiv]

The addition of hybrid vehicles, although crucial to the continued growth of their market, is only a part of successfully reducing the emissions of vehicles, hybrid and

otherwise. New technologies that we will find in future vehicles present a world of options for reducing emissions. Regenerative braking, which is already incorporated in hybrid vehicles, is a means to return friction energies to the batteries of the vehicle. Advancements in regenerative brakes will lead to more efficient and better systems of energy reclamation. A new development by the Ford company known as vehicle launch assist is able to reclaim the energies used in bringing a vehicle to a stop by storing it as hydraulic pressure; when the vehicle accelerates from stop the hydraulic pressure is released, thereby eliminating the large amounts of fuel used to move a resting vehicle.[xv]

It is only in our best interest to examine cleaner ways with which to travel. In fact, of the general public who use some form of transportation to get to work, only 5.2 percent use a form of public transportation and only twice that number carpool.[xvi]

Methodology:

The first step in determining whether the hybrid car will have any effect upon the environment is to analyze the situation into which it will be placed. The city of Worcester, the second largest city in Massachusetts, contains a populace that needs to move, whether to work or play. No matter what form of transportation they choose there will be some impact upon the environment, excepting some forms of transit such as walking, bicycling, or another zero emissions activity. As 80% of the Massachusetts population owns automobiles we feel it is safe to assume that the population of our city represents the driving population.

Determining the exact population of Worcester drivers is a rather complicated task. Using the percentage above above, we simply need to determine what the Worcester population is. Worcester County, not city, is listed as having a population of 751,000, and Worcester City, 173,000, but neither of these figures was used because the Worcester City data fails to take into account travelers from outside the city, and Worcester County incorporates people who may very well never set foot in Worcester City. The population that will best serve our study actually comes from the U.S. Department of Labor, Bureau of Labor Statistics; there are 254,900 civilian laborers in the Worcester Metropolis area. This figure contains the Worcester City population and all the individuals who may travel from outside the city for work.

To examine the amount of pollution produced by the vehicles traveling in the city of Worcester we assume that a vehicle traveling into, through, or out of the city travels a certain distance. Worcester has an average diameter of approximately 6.9 miles, and

therefore each vehicle will travel 7 miles. This should account for vehicles traveling more or less than this distance in the city. It is assumed that each vehicle is driven 365 days per year, 261 of which are weekdays, and 104 of which are weekends. On a weekday the average vehicle will be driven to and from work, 7 miles in each direction, and on a weekend the vehicle will be driven 3.5 miles in each direction for pleasure purposes. Note that this does not take into account the fact that some vehicles are driven more or less than this in real life, whether on long trips or not being used at all for that day this merely reflects an average amount of miles produced in Worcester city by repetitive behavior such as commuting.

With automakers cranking out new models every year, and the popularity of certain types of automobiles growing and shrinking, the actual percentage of each type of vehicle on the road, SUV's, pickup's, small cars, medium-sized cars, etc., is hard to determine. Here we can make the assumption that the percentage of each vehicle type on the road is also reflected in the number of models of that have been sold, or designed. Although this seems sound, we felt that in the interest of a correct, local sample, actual traffic should be examined (the models produced figures can be found in Appendix I, Table 6). Table 3 shows the data gathered from traffic samples in the city of Worcester. Approximately 1500 vehicles make up the data sample.

Table 3 - Percentage of Vehicle Types in Worcester

New		Old	
Light Duty Trucks	28	Light Duty Trucks	20
Small Cars	21	Small Cars	20
Midsize/Large Cars	51	Midsize/Large Cars	60
Total	100%	Total	100%

Large commercial and industrial vehicles will not be included in our study due to the near impossibility of replacing these vehicles with the current hybrid technology.

The Worcester sample data is then broken down even further to determine the age distribution of the vehicles traveling the streets. Table 4 shows the breakdown that is used to do the emissions analysis. The age classifications are divided in such a way as to correspond to dates EPA regulations were enacted.[xvii]

Table 4 - Age Distribution of Vehicles on the Road (Percent)

1996-2002	45
1992-1995	30
1982-1991	22
Pre 1982	3
Total	100%

The results of the Worcester traffic samples are applied to the following categories of vehicles in order to obtain the fully decomposed distribution of vehicle types in Worcester. Table 5 shows the factors that are applied to new vehicles to obtain a detailed decomposition according to the recent EPA standards.

Table 5 - Tabulated Vehicle Distribution for New Vehicles (Percent)

	LDT	Small Cars	Mid/Large Cars
ZEV	0.21	0.26	0
SULEV	0.86	1.06	0.36
ULEV	4.5	15.04	19.13
LEV	51.82	65.17	70.4
TLEV	1.5	9.5	7.94
Tier 1	41.11	8.97	2.17
Total	100%	100%	100%

For vehicles older than the 1996 model year, the only decomposition that will be recognized is whether the vehicles are Light Duty Trucks (LDT) or Light Duty Vehicles (LDV). To make this calculation, take the values of small cars and midsize/large cars from Table 1 and add them together. Eighty percent of the older vehicles are LDV's, and twenty percent are LDT's. The final breakdown is as follows:

- "New" Vehicles (model years 1996-2002)
    - Light Duty Trucks (LDT) which include Pickup Trucks, SUV's, and Vans
        - Tier 1
        - Traditional Low Emissions Vehicle (TLEV)
        - Low Emissions Vehicle (LEV)
        - Ultra Low Emissions Vehicle (ULEV)
        - Super Ultra Low Emissions Vehicle (SULEV)
        - Zero Emissions Vehicle (ZEV)
    - Small Cars
        - Tier 1
        - Traditional Low Emissions Vehicle (TLEV)
        - Low Emissions Vehicle (LEV)
        - Ultra Low Emissions Vehicle (ULEV)
        - Super Ultra Low Emissions Vehicle (SULEV)
        - Zero Emissions Vehicle (ZEV)
    - Midsize to Large Cars
        - Tier 1
        - Traditional Low Emissions Vehicle (TLEV)
        - Low Emissions Vehicle (LEV)
        - Ultra Low Emissions Vehicle (ULEV)
        - Super Ultra Low Emissions Vehicle (SULEV)
        - Zero Emissions Vehicle (ZEV)

- "Old" Vehicles (Vehicle manufactured before model year 1996)
    - 1992 thru 1995 model year vehicles
        - Light Duty Trucks (LDT's)
        - Light Duty Vehicles (LDV's)
    - 1982 thru 1991 model year vehicles
        - Light Duty Trucks (LDT's)
        - Light Duty Vehicles (LDV's)
    - Vehicles manufactured before 1982
        - Light Duty Trucks (LDT's)
        - Light Duty Vehicles (LDV's)

Due to the strict EPA regulatory process involved with the manufacture and use of automobiles recently, emissions statistics can be found for each model of automobile sold to the public. These statistics, shown in Table 6, are then applied directly to the vehicle distribution listed above.

Table 6 - Emissions Data (Grams/Mile)

	CO	NOx	HC
New Vehicles			
ZEV	0	0	0
SULEV	1	0.02	0.01
ULEV	1.7	0.2	0.048*
LEV	3.4	0.2	0.09*
TLEV	3.4	0.4	0.14*
Tier 1	4.2	0.6	0.31
Old Vehicles			
LDV ('92-'95)	3.4	1	0.41
LDT ('92-'95)	10	1.2	0.67
LDV ('82-'91)	4.2	1	0.80**
LDT ('82-'91)	10.9***	1.2	0.80**
LDV (Pre '82)	23.8***	2.3***	1.9***
LDT (Pre '82)	24.1***	2.7***	2.2***

* HC is calculated by NMOG + HCHO

** In this timeframe, HC was not regulated. Instead, Volatile Organic Compounds (VOC) were the standard and will be considered nearly equivalent to HC.

*** Average Value

The EPA relaxes the emissions regulations of vehicles as they age. In accordance with the EPA regulation relaxation over time, older vehicles will be based on statistics of 5 years/ 60,000 miles or 10 years/100,000 miles for each specific vehicle category.[xviii] The accuracy of this data allows us many avenues upon which to pursue the problem of determining the emissions released by the automobiles currently running Worcester's roads.

The hybrid vehicles, which fit into an EPA ranking shared by virtually no other vehicle, represent the cleanest form of gasoline based internal-combustion transportation available, SULEV. It is safe to assume that at some point in the not too distant future the hybrid vehicle will become a more popular and cost efficient choice for consumers, and therefore the presence of them on today's streets may just foreshadow their presence in future years. To examine the benefits of this change, we propose to numerically change certain percentages of New and Old small cars, midsize/large cars and minivans, and SUV/pickup's and large vans into hybrid vehicles with emissions that reflect the SULEV cutoffs. Converting the aforementioned percentages of each vehicle type to the SULEV standard and reworking the pollution equations can achieve this.

These calculations allow the prediction of a change in total emissions as certain percentages and types of automobiles are replaced with hybrid vehicles. This allows us the ability to make recommendations as to which type of vehicle is best suited to hybrid technology, in terms of greatest reduction in emissions. The calculations will also prove whether or not the hybrid vehicle is a worthy venture, and whether this technology will really help mankind towards a cleaner future.

To this point calculations have been for the chemicals HC, CO, and NOx, another very important gas to be aware of is CO_2. CO_2 is not examined in depth in this study due largely to the absence of any federal regulations on automobile emissions when it comes to this gas. CO_2 is one of the largest volumes of green house gases released every year, and is therefore important enough that we mention it here.

Tailpipe emissions are inextricably tied to the amount of fuel used by an internal combustion engine, therefore the better miles per gallon a vehicle can achieve, the less

pollutants. CO_2 for example has a very direct relationship with the combustion of gasoline, for every gallon of the fuel burned 20 pounds of CO2 will be released into the atmosphere. Examining the fuel efficiencies of a hybrid vehicle when compared to the average efficiency of on road vehicles can give us a fairly good idea of the pollution reductions we incur with each Hybrid vehicle added to the road.

Results:

The following Figures display the results of the calculations done with regards to the amount of pollution in several test cases. Each graph represents a different test case in which a noted percentage of automobiles from a certain category were replaced with Hybrids.

Figure 1- Replacing 25% of all Vehicles with Gas-Electric Hybrids Vehicles

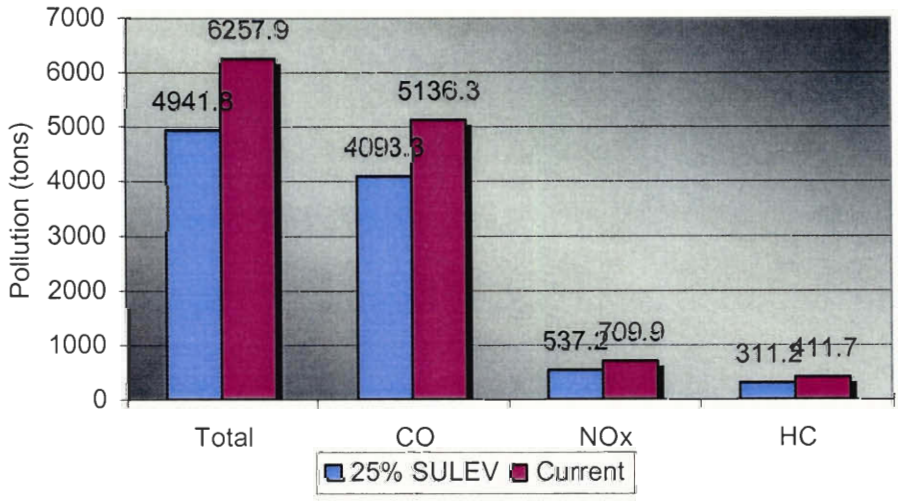


Figure 2 - Replacing 50% of all Vehicles with Gas-Electric Hybrids Vehicles

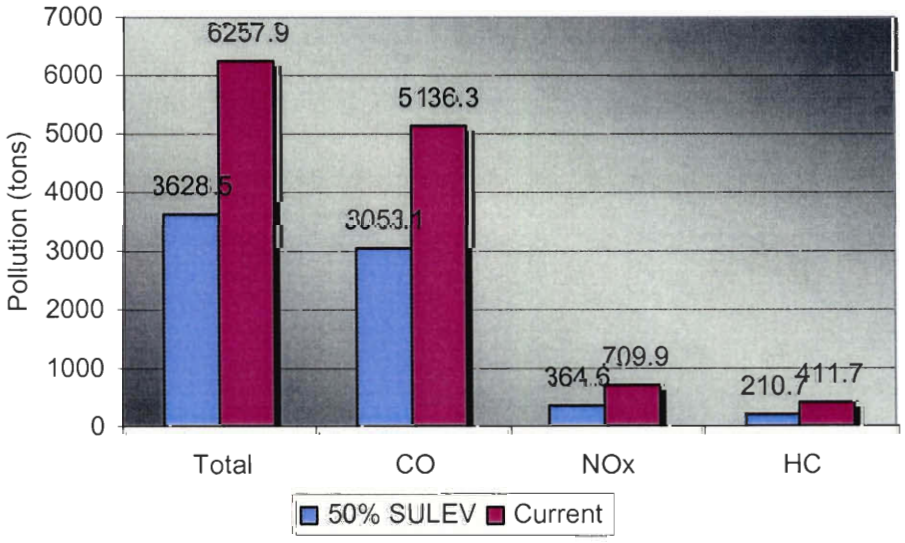


Figure 3 - Replacing 100% of all Vehicles with Gas-Electric Hybrids Vehicles

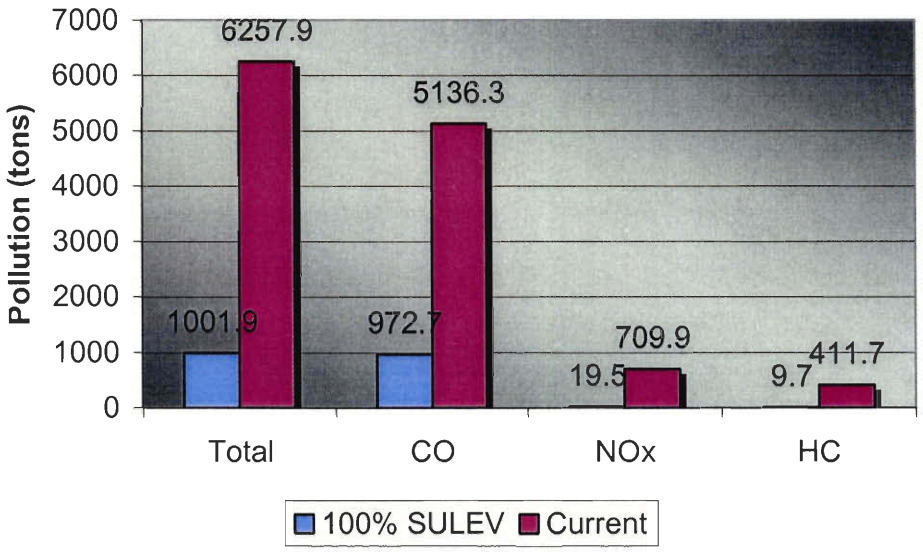
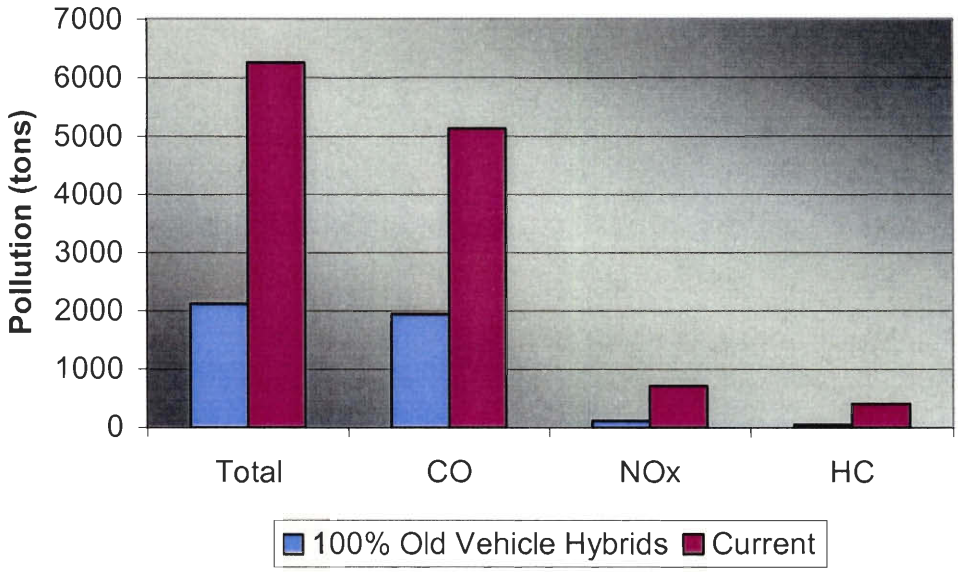


Figure 4 - Replacing 100% of all Old Vehicles with Gas-Electric Hybrids Vehicles



The results from the four preceding scenarios show us that replacing conventional vehicles with hybrid vehicles can be very advantageous. The results in fact show us that if we were to phase out only the "old" vehicles with hybrids we could reduce the

pollution by nearly the same amount as by replacing approximately 75 percent of all vehicles.

Another area of interest is determining which type of vehicle is best suited for hybrid technology. The following three charts show the linear reduction in emissions, for our three focus chemicals. In this test we replaced Small Cars and compared the outcome to replacing Light Duty Trucks; SUV's, pickups, large vans.

Figure 5 - Total CO Emissions, Replacing Small Cars vs LDT's

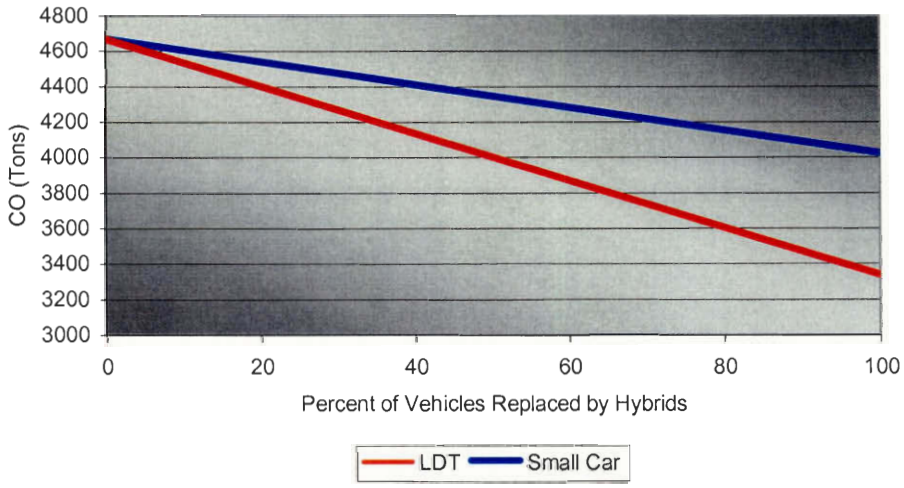


Figure 6 - Total HC Emissions, Replacing Small Cars vs LDT's

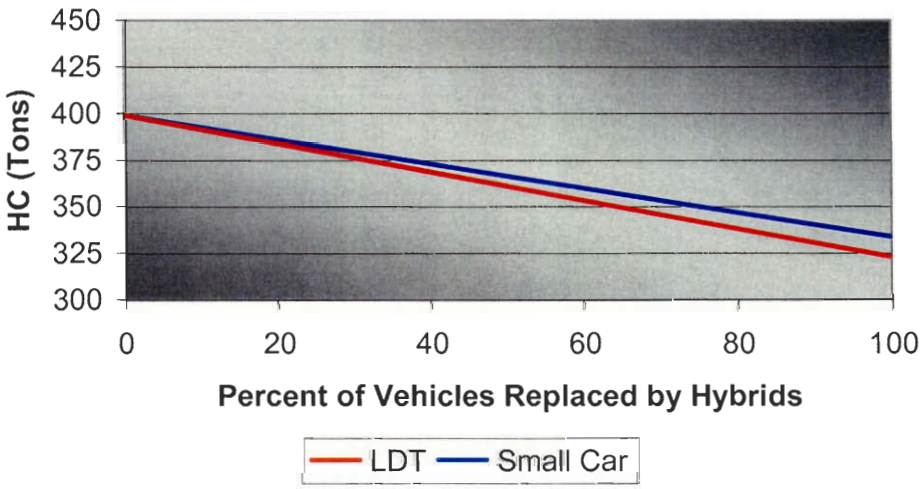
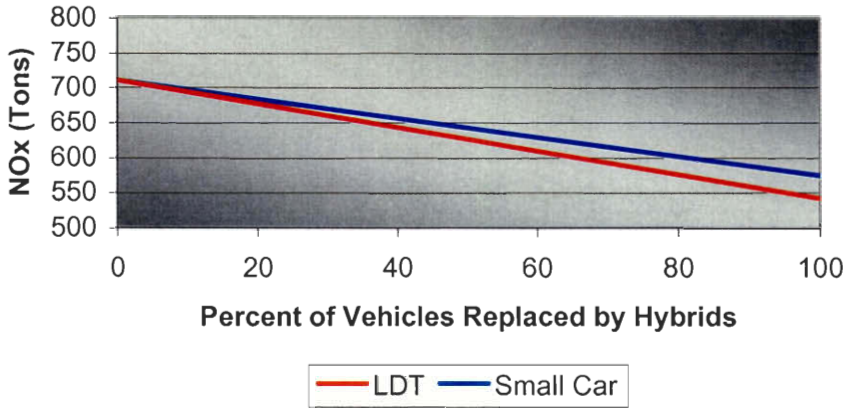


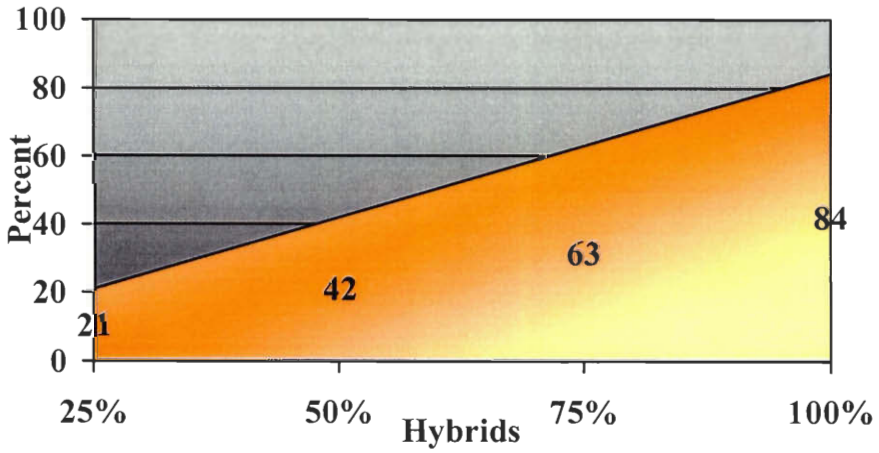
Figure 7 -Total NOx Emissions, Replacing Small Cars vs LDT's



It is obvious that replacing the more popular heavily polluting LDTs will reduce the emissions by a far greater amount than merely replacing an already clean vehicle.

When examining the replacement of all vehicles with Hybrid vehicles we discover a linear relationship between the number of vehicles replaced and the amount of pollution reduced.

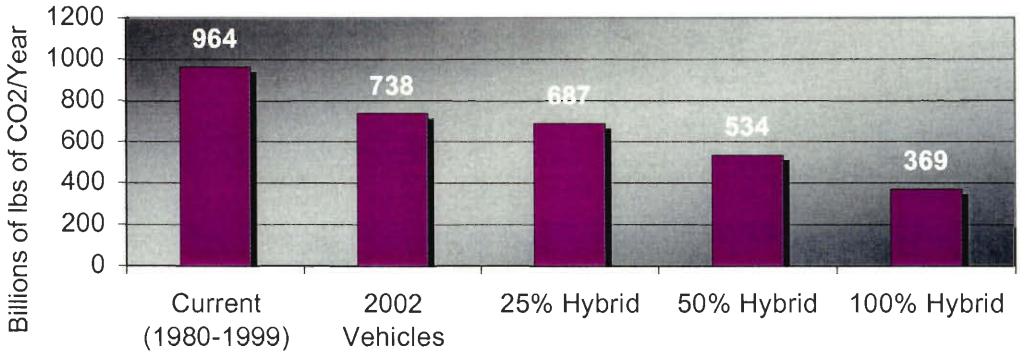
Figure 8 - Pollution Reduction



One can see from the graph that if all vehicles currently on the road where replaced by Hybrids we would produce merely 16% of our current pollution tonnage.

Examining the Hybrid impact on CO_2 shows similar trends and the other chemicals we have looked at so far. An addition of Hybrid vehicles will result in a nearly linear decrease in the tonnage of CO_2 released into the atmosphere.

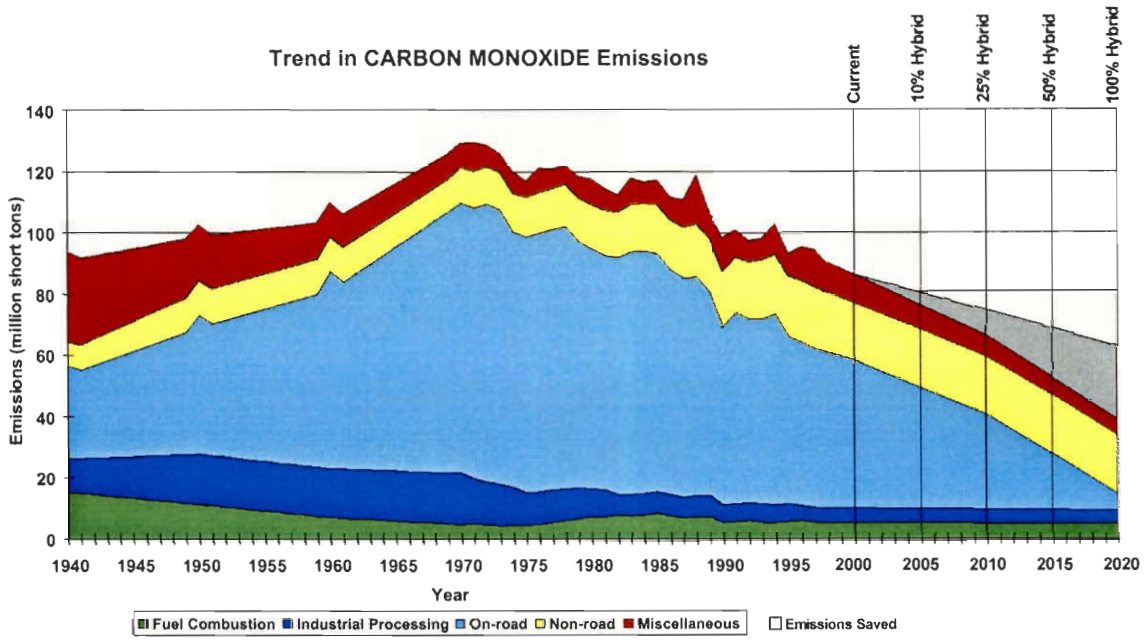
Figure 9 - CO2 Scenarios



The following three figures are based upon EPA data collected through 1998[xix]. Data after 1998 is projected from the calculations preformed on Worcester, MA and has been expanded to encompass national emissions trends. In all cases, current trends from all polluting sources were projected and then emissions due to automobiles were reduced according to the following proposal:

- Within five years 10% of all automobiles will be hybrids
- Within ten years 25% of all automobiles will be hybrids
- Within fifteen years 50% of all automobiles will be hybrids
- After twenty years all automobiles will be hybrids

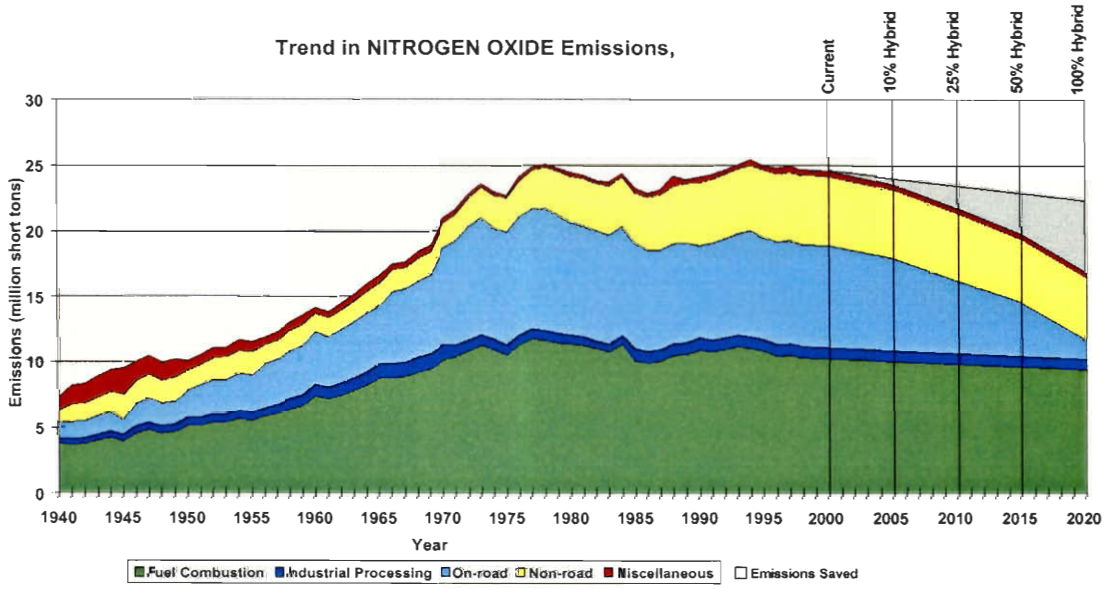
Pollution Timeline 1 – Carbon Monoxide Trend



Pollution Timeline 1[xx] is a representation of the national trend in carbon monoxide emissions and a prediction of future trends. *Fuel Combustion*, (power plants, home heating, etc) currently accounts for approximately seven to ten percent CO emissions and is not increasing nor decreasing significantly. *Industrial Processing*, (manufacturing, chemical processing, etc) CO emissions are also remaining fairly constant at about seven percent of the total. *On-Road* (automotive) sources show the largest amount of pollution, and also the largest variation in this figure. *Non-Road* (construction equipment, lawn mowers, etc) show a slight increasing trend in CO emissions, however during the decade of the 1990's the trend begins to level out. *Miscellaneous* sources have held relatively constant for the past several decades.

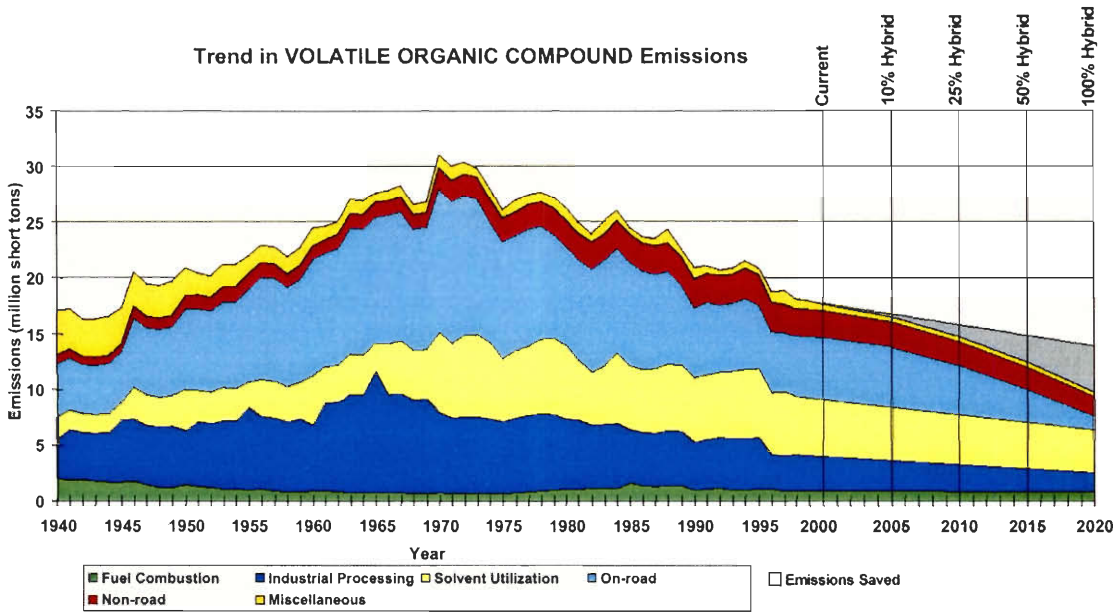
Prior to 1970, there was no significant restriction on automotive emissions. As the number of vehicles increased, the CO emissions increased proportionally. In the early 1970's, the catalytic converter was introduced to new vehicles and the affect in the CO emissions is clearly obvious in Pollution Timeline 1 as the trend peaks and begins to decrease. Since that time, technology has been increasing that can lower CO emissions such that there is a decreasing trend in auto emissions. In the prediction of future trends, CO emissions can be reduced significantly by the implementation of hybrid vehicles. By the year 2020, it is proposed that total CO emissions from automobiles will be less than ten percent of the total CO emissions, and the total CO emissions could be half of what they are currently. After 2020 there will be a national annual savings of approximately 25 million tons of CO if hybrid vehicles are implemented as proposed.

Pollution Timeline 2 - Nitrous Oxide Trend



Unlike the carbon monoxide trend, the nitrous oxide trend shown in Pollution Timeline 2[xxi] does not show a significant decline in total emissions through the year 2000. *Fuel Combustion, On-Road,* and *Non-Road* sources account for the majority of NOx emissions. Since the 1970's these sources show a leveling out of NOx emissions with no indication of a decline. But if the hybrid vehicle proposal were implemented, by year 2020 there would be an annual savings of twelve million tons of nitrous oxide emissions nationally. The air quality in terms of NOx pollutants would be back to a level similar to what it was in the 1960's.

Pollution Timeline 3 - Volatile Organic Compound Trend



Pollution Timeline 3[xxii] shows the trend in volatile organic compound emissions in the United States. Note that there is an additional category in this figure that was not present in the previous two figures – *Solvent Utilization. Solvent Utilization* consists of VOC emissions caused by the use of products like paint thinner, aerosol sprays, and

disinfectants[xxiii]. This category is responsible for nearly one quarter of all VOC emissions. Automotive sources are also currently responsible for approximately twenty-five percent of volatile organic compound emissions. Since the 1970's there has been a decreasing trend in automotive VOC emissions, but the implementation of the hybrid proposal will accelerate the decrease. By 2020, the hybrid vehicles will be saving the nation about nine million tons of VOC emissions annually.

Conclusions:

The gradual introduction of hybrid vehicles into the automotive market place will yield startling changes in lives and pollution statistics across the globe. Wherever vehicles are heavy polluters we will see a drastic drop in the amount of pollution produced per vehicle, meaning cleaner air for everyone. Bearing in mind that the hybrid vehicle is not pollution free, but merely vastly cleaner by today's standards than nearly every other vehicle on the road, we can calculate our reduction in pollution from today's emissions output.

If Congress passed a bill tomorrow that mandated a replacement of a percentage of the vehicles on the road with hybrid vehicles we could expect some of the following changes. If we were to replace 10% of all vehicles currently on the road with hybrid vehicles we would see an 8.4% decrease in the amount of pollution produced by automobiles. A 25% hybrid substitution would yield a 21% reduction, 50% substitution would yield 42% reduction, and if 100% of the vehicles on the road were hybrid vehicles the yearly output would be 84% less than it is today.

Similar to EPA efforts to clean skies, a gradual implementation of a series of requirements for new vehicles resulting in an increased presence of hybrid vehicles on the road would lead to drastic reductions in annual pollution by automobiles. Realizing that a 100 percent replacement of vehicles with hybrids is not necessarily feasible nor the correct solution at this time, one must bear in mind that each non-hybrid vehicle replaced with a hybrid is a substantial pollution savings.

The most fortuitous immediate solution to lowering the pollution output of vehicles each year would be to implement a phase out of older vehicles, whether with

merely newer model vehicles, or with hybrids this would vastly decrease the annual pollution output. Vehicles produced before 1996 a mere 55% of the on road vehicles at this time account for nearly 80% of the pollution produced each year. Ideally these vehicles should be replaced by hybrids similar to simply eliminating 55% of the polluting vehicles on the road.

Appendix I:

The following emissions data was obtained from the Code of Federal Regulations, 40 CFR part 86 subpart R.

Table 1 - Emissions Standards

Pollutant	Current Federal Standard – Tier 1 *(grams/mile)*
HC[4]	0.31
CO[5]	4.2
NO_x[6]	0.6

Table 2 - A Comparison of Emissions Standards

Pollutant	Clean Car Campaign – SULEV Standard *(grams/mile)*	Current Federal Standard – Tier 1 *(grams/mile)*	Reduction *(percent)*
HC	0.01	0.31	97%
CO	1.0	4.2	76%
NO_x	0.02	0.6	97%

Table 7 - Percentage of Vehicle Types in Worcester

New		Old	
Light Duty Trucks	28	Light Duty Trucks	20
Small Cars	21	Small Cars	20
Midsize/Large Cars	51	Midsize/Large Cars	60
Total	100%	Total	100%

[4] HC : Hydrocarbons.
[5] CO : Carbon Monoxide.
[6] NO_x : Nitrous Oxides.

Table 8 - Age Distribution of Vehicles on the Road (Percent)

1996-2002	45
1992-1995	30
1982-1991	22
Pre 1982	3
Total	100%

Table 9 - Tabulated Vehicle Distribution for New Vehicles (Percent)

	LDT	Small Cars	Mid/Large Cars
ZEV	0.21	0.26	0
SULEV	0.86	1.06	0.36
ULEV	4.5	15.04	19.13
LEV	51.82	65.17	70.4
TLEV	1.5	9.5	7.94
Tier 1	41.11	8.97	2.17
Total	100%	100%	100%

Table 10 - Emissions Data (Grams/Mile)

	CO	NOx	HC
New Vehicles			
ZEV	0	0	0
SULEV	1	0.02	0.01
ULEV	1.7	0.2	0.048*
LEV	3.4	0.2	0.09*
TLEV	3.4	0.4	0.14*
Tier 1	4.2	0.6	0.31
Old Vehicles			
LDV ('92-'95)	3.4	1	0.41
LDT ('92-'95)	10	1.2	0.67
LDV ('82-'91)	4.2	1	0.80**
LDT ('82-'91)	10.9***	1.2	0.80**
LDV (Pre '82)	23.8***	2.3***	1.9***
LDT (Pre '82)	24.1***	2.7***	2.2***

* HC is calculated by NMOG + HCHO

** In this timeframe, HC was not regulated. Instead, Volatile Organic Compounds (VOC) were the standard and will be considered nearly equivalent to HC.

*** Average Value

Table 6 - EPA Ranking percentages for the 2001 Model Year

SUV-Pickup-Van	Total	467	% of Total
	LEV	242	51.82
	TLEV	7	1.50
	T1	192	41.11
	ULEV	21	4.50
	SLEV	4	0.86
	ZEV	1	0.21
Large-Mid-Minivan	Total	277	% of Total
	LEV	195	70.40
	SLEV	1	0.36
	T1	6	2.17
	TLEV	22	7.94
	ULEV	53	19.13
Small Car	Total	379	% of Total
	LEV	247	65.17
	SLEV	4	1.06
	T1	34	8.97
	TLEV	36	9.50
	ULEV	57	15.04
	ZEV	1	0.26

Compiled from the EPA Green Vehicle Guide.

Figure 1- Replacing 25% of all Vehicles with Gas-Electric Hybrids Vehicles

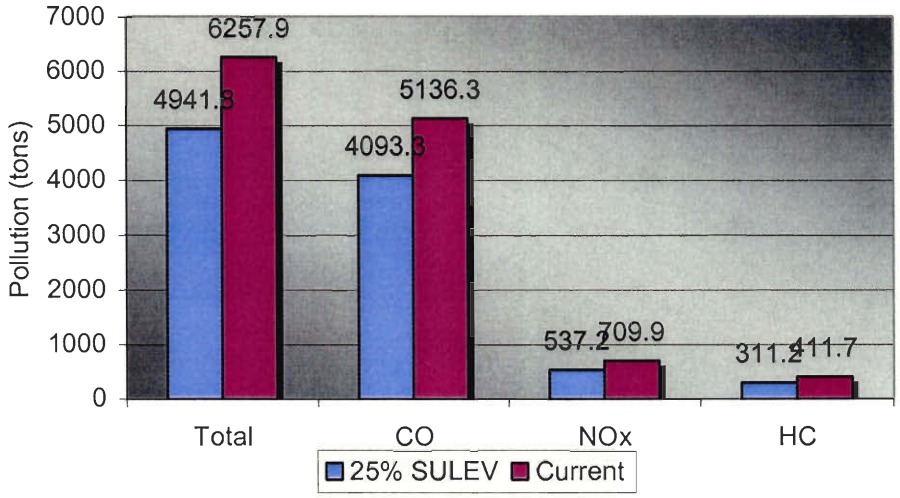


Figure 2 - Replacing 50% of all Vehicles with Gas-Electric Hybrids Vehicles

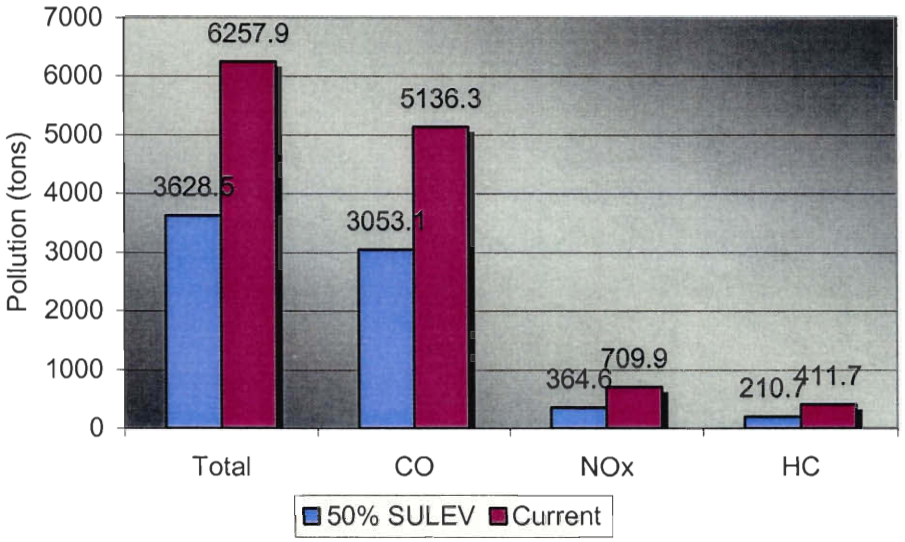


Figure 3 - Replacing 100% of all Vehicles with Gas-Electric Hybrids Vehicles

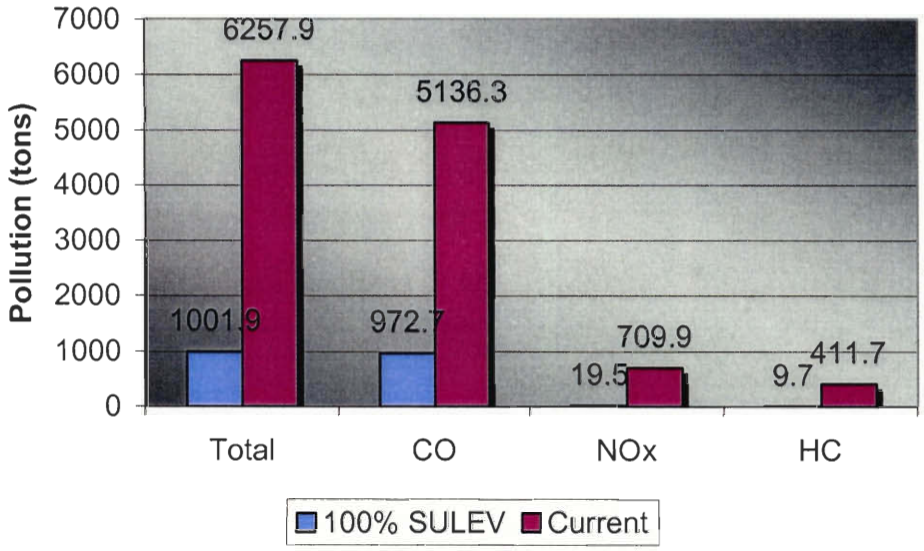


Figure 4 - Replacing 100% of all Old Vehicles with Gas-Electric Hybrids Vehicles

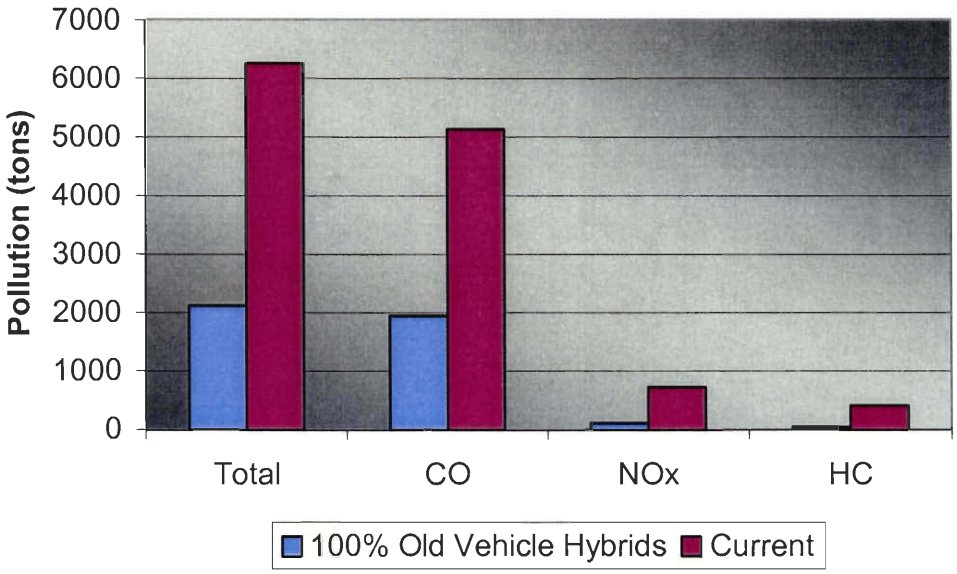


Figure 6 - Total HC Emissions, Replacing Small Cars vs LDT's

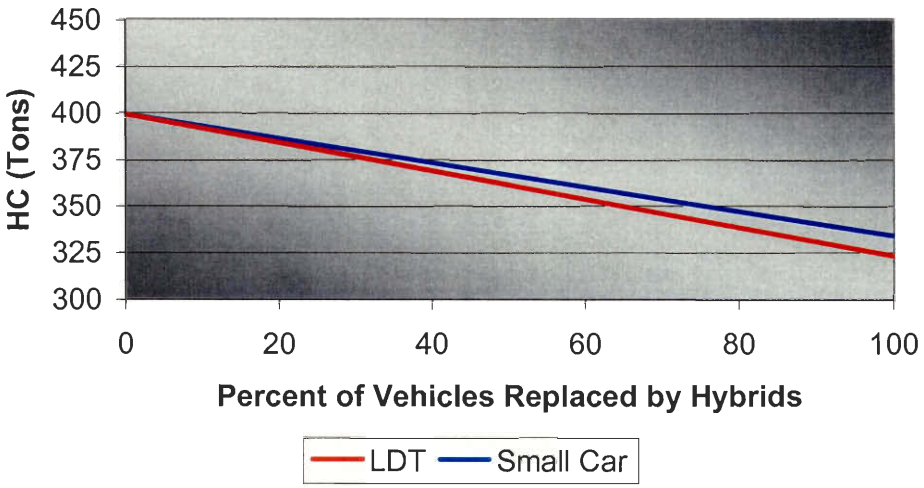


Figure 7 -Total NOx Emissions, Replacing Small Cars vs LDT's

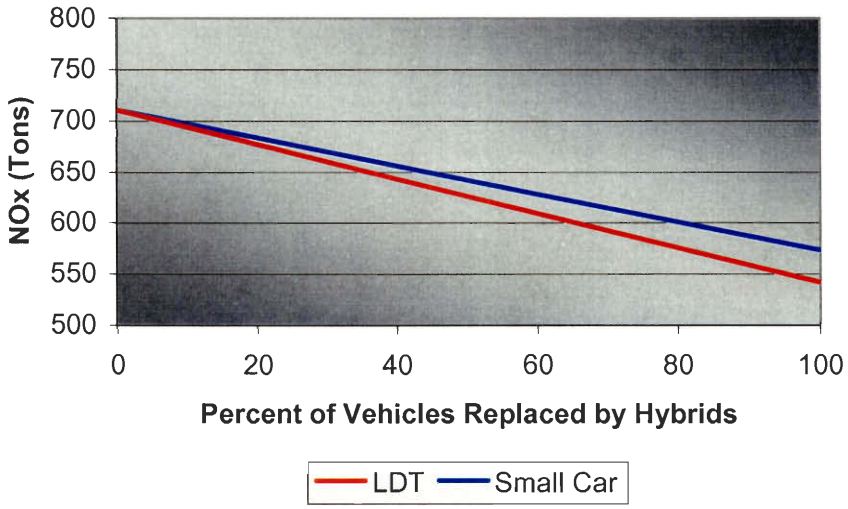


Figure 8 - Pollution Reduction

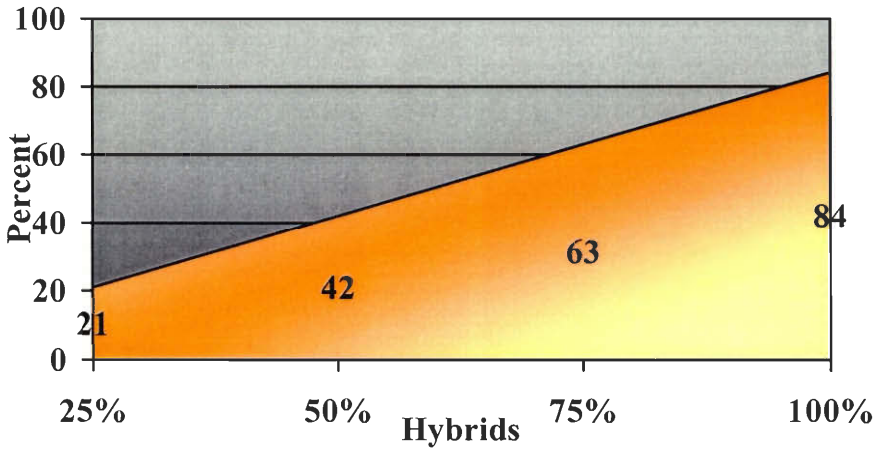
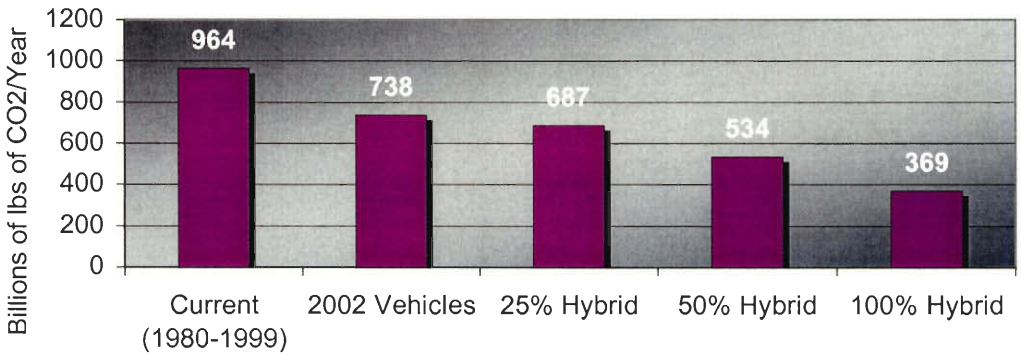
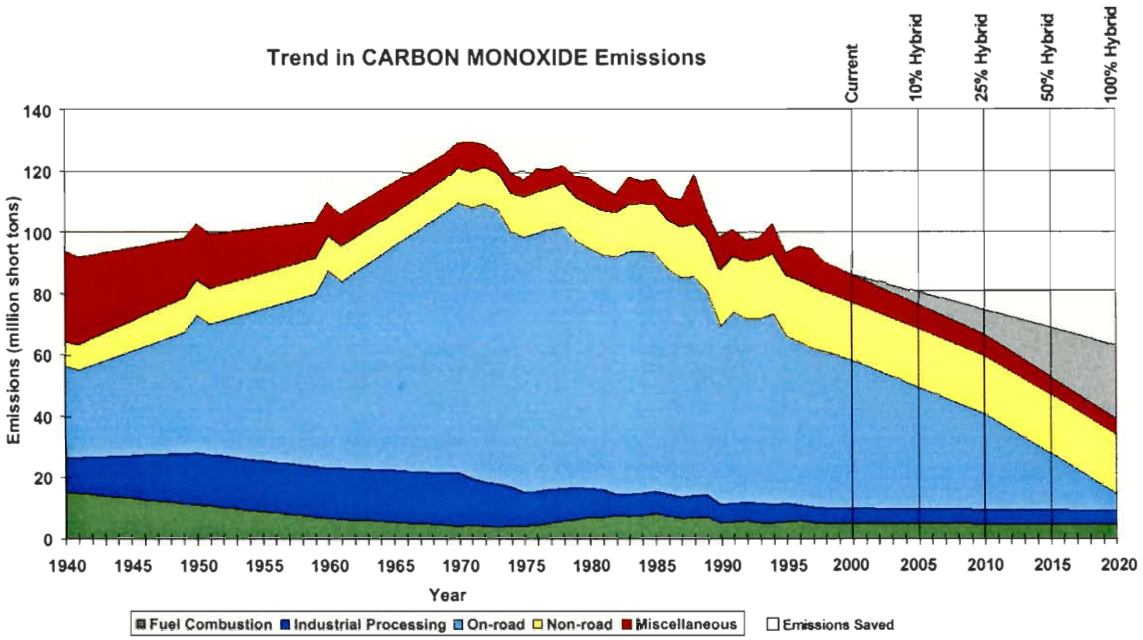


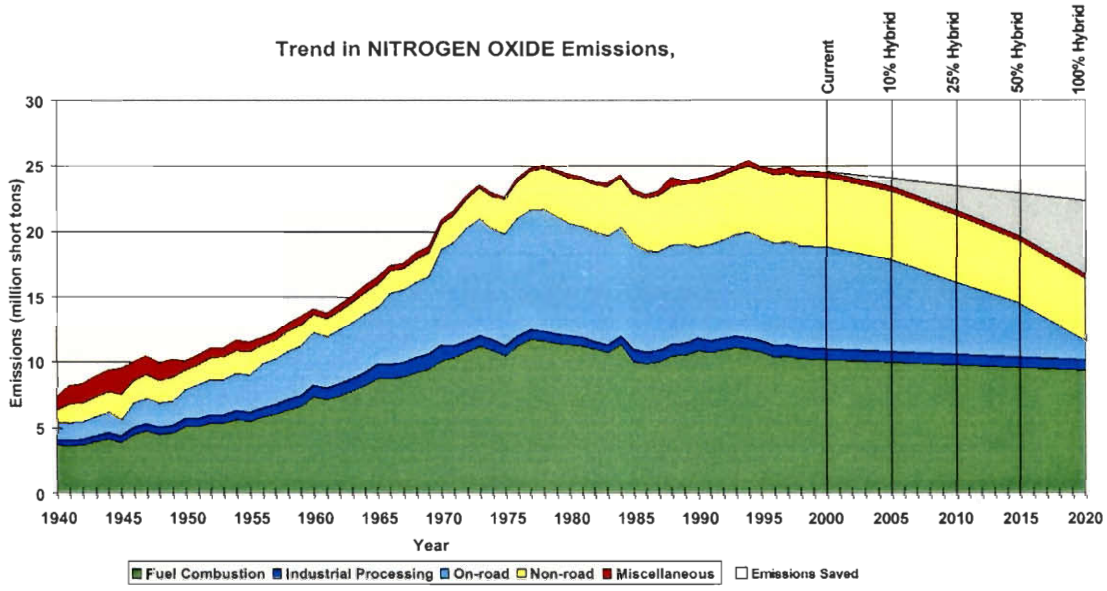
Figure 9 - CO2 Scenarios



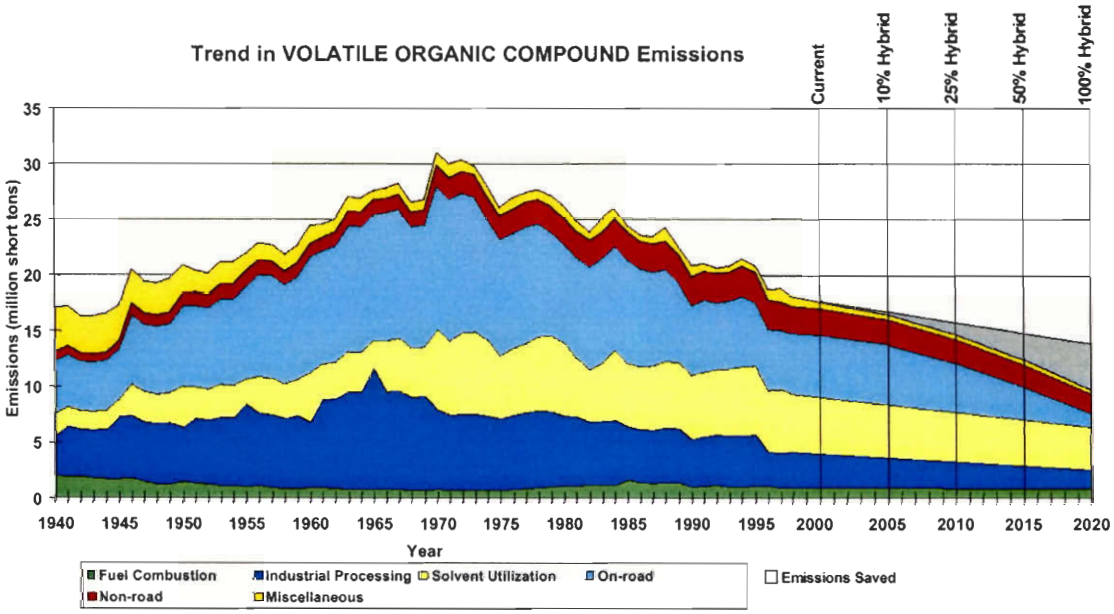
Pollution Timeline 4 – Carbon Monoxide Trend



Pollution Timeline 5 - Nitrous Oxide Trend



Pollution Timeline 6 - Volatile Organic Compound Trend



Appendix II:

Carbon Oxides – Also referenced as CO and CO_2.

Carbon Dioxide - A colorless, odorless, incombustible gas, CO_2, formed during respiration, combustion, and organic decomposition and used in food refrigeration, carbonated beverages, inert atmospheres, fire extinguishers, and aerosols. Also called carbonic acid gas. [xxiv]

Carbon Monoxide – A colorless, odorless, highly poisonous gas, CO, formed by the incomplete combustion of carbon or a carbonaceous material, such as gasoline. [xxv]

Carcinogens – Substances that increase the risk of neoplasms in humans or animals. Both genotoxic chemicals, which affect DNA directly, and nongenotoxic chemicals, which induce neoplasms by other mechanisms, are included. [xxvi]

Emission – Pollutants spewed from an internal-combustion engine.

Hydrocarbons – Also referenced as HC. Any of numerous organic compounds, such as benzene and methane, that contain only carbon and hydrogen.[xxvii]

Hybridization – The combination of electric and internal-combustion engines to create a new engine which benefits from both technologies.

Internal-combustion Engine - An engine, such as an automotive gasoline piston engine or a diesel, in which fuel is burned within the engine proper rather than in an external furnace, as in a steam engine. [xxviii]

Nitrous Oxides – Also referenced as NOx. Nitrogen oxides (NO, NO_2, and NO_3.; or NO_x for short) are exhaust products from factories and automobiles. NOx is produced during the high temperature combustion of all fossil fuels. In addition to contributing to ozone formation, some nitrogen oxides, such as NO_2 (nitrogen dioxide), are corrosive by themselves and can cause respiratory problems.[xxix]

Low Emission Vehicle – (LEV) An intermediate California standard about twice as stringent as Tier 1.[xxx]

Super Low Emission Vehicle – (SLEV or SULEV) a California standard even tighter than ULEV and prohibiting emissions of fuel vapors. [xxxi]

Tier 1 – (T1) The prevailing Federal (EPA) standard .[xxxii]

Transitional Low Emission Vehicle – (TLEV) The weakest California standard [xxxiii]

Ultra Low Emission Vehicle – (ULEV) A stronger California standard emphasizing very low HC emissions [xxxiv]

Zero Emission Vehicle – (ZEV) A California standard, prohibiting any tailpipe emissions [xxxv]

Sources:

[i] History of the Electric Automobile Hybrid Electric Vehicles, Ernest H. Wakefield, Society of Automotive Engineers, PA, 1998, pg. 18-21
[ii] Formaldehyde : http://www.lindane.org/chemicals/formaldehyde.htm
[iii] Milestones in Auto Emissions Control : http://www.epa.gov/otaq/12-miles.htm
[iv] The Clean Car Campaign | Green Vehicle Standard: http://www.cleancarcampaign.org/standard.html
[v] The Clean Car Campaign | Green Vehicle Standard: http://www.cleancarcampaign.org/standard.html
[vi] GreenCars.com, the green book online: http://www.greenercars.com/byclass.html
[vii] About the EPA's rating system : http://www.epa.gov/autoemissions/about.htm
[viii] *Air Quality Statistics by City,* United States Environmental Protection Agency - Office of Air and Radiation, 2000
[ix] MHD Transportation facts: http://www.state.ma.us/mhd/transfacts.htm
[x] MRMV-MDEP: http://www.vehicletest.state.ma.us/faqs.htm
[xi] Hybridcars.com : http://www.hybridcars.com/ford_escape.htm
[xii] Ford HEV : http://www.hybridford.com/index.asp
[xiii] Toyota.com : http://motorshow.toyota-europe.com/g/g01_30.html
[xiv] Toyota.com : http://motorshow.toyota-europe.com/g/g01_30.html
[xv] Sunday Telegram, Worcester, Mass.,01/27/2002 Section J
[xvi] *P047. MEANS OF TRANSPORTATION TO WORK FOR WORKERS 16 YEARS AND OVER - Universe: Workers 16 years and over*, US Census Bureau, 2000 Census
[xvii] Center for Transportation Analysis, National Public Transportation Survey 1995
[xviii] Code of Federal Regulations, 40 CFR part 86 subpart R
[xix] *National Air Pollutant Emission Trends, 1900-1998* United States Environmental Protection Agency – Office of Air Quality Planning and Standards, March 20001
[xx] Expanded from ***Figure 3-2: Trend in Carbon Monoxide Emissions***, *1940-1998, National Air Pollutant Emission Trends, 1900-1998* United States Environmental Protection Agency – Office of Air Quality Planning and Standards, March 2001. pp 3-22
[xxi] Expanded from ***Figure 3-3: Trend in Nitrogen Oxide Emissions***, *1940-1998, National Air Pollutant Emission Trends, 1900-1998* United States Environmental Protection Agency – Office of Air Quality Planning and Standards, March 2001. pp 3-23
[xxii] Expanded from ***Figure 3-4: Trend in Volatile Organic Compound Emissions***, *1940-1998, National Air Pollutant Emission Trends, 1900-1998* United States Environmental Protection Agency – Office of Air Quality Planning and Standards, March 2001. pp 3-24
[xxiii] *The Inside Story: A Guide to Indoor Air Quality* United States Environmental Protection Agency and the United States Consumer Product Safety Commission Office of Radiation and Indoor Air (6604J)
EPA Document # 402-K-93-007, April 1995

Appendix II

[xxiv] http://www.dictionary.com
[xxv] http://www.dictionary.com
[xxvi] http://www.dictionary.com
[xxvii] http://www.dictionary.com
[xxviii] http://www.dictionary.com
[xxix] http://www.neci.sr.unh.edu/glossary/nox.html
[xxx] http://www.aceee.org/greenguide/tab-temp.htm
[xxxi] http://www.aceee.org/greenguide/tab-temp.htm
[xxxii] http://www.aceee.org/greenguide/tab-temp.htm
[xxxiii] http://www.aceee.org/greenguide/tab-temp.htm
[xxxiv] http://www.aceee.org/greenguide/tab-temp.htm
[xxxv] http://www.aceee.org/greenguide/tab-temp.htm

Calculations

Replacing 10% of all new Vehicles w/Hybrids

billion_miles := $10^9 \cdot mi$

million_miles := $10^6 \cdot mi$

Assumptions:

Vehicles traveling through Worcester Travel an average of 7 miles each

Travel_distance := $7 \cdot mi$

Work_days := $261 \cdot day$

Week_ends := $104 \cdot day$

City Data:

Worcester_population := 254900 people

Vehicles_per_person := 0.79

Percentages of Vehicle Types:

Newer Vehicles:

SUV := 0.275 SmC := 0.21 LMM := 0.51

Older Vehicles:

SUV_{old} := 0.20 SmC_{old} := 0.20 LMM_{old} := 0.60 LDT% := SUV_{old}

LDC% := $SmC_{old} + LMM_{old}$

Age distribution of Vehicles on the Roads:

1996 - 2002 $V_{9602} := 0.45 \cdot (0.90)$

1992 - 1995 $V_{9295} := 0.30$

1982 - 1991 $V_{8291} := 0.22$

Pre 1982 $V_{P82} := 0.03$

$V\%_{new} := 0.45$

$V\%_{old} := 0.55$ 55% of all worcester vehicles are "old"

Transitional Low Emissions Vehicle Data:

TLEV_NMOG := $0.125 \cdot \frac{gm}{mi}$ TLEV_NOx := $0.4 \cdot \frac{gm}{mi}$

TLEV_CO := $3.4 \cdot \frac{gm}{mi}$ TLEV_HCHO := $0.015 \cdot \frac{gm}{mi}$

TLEV_HC := TLEV_NMOG + TLEV_HCHO

TLEV_HC = $0.14 \frac{gm}{mi}$

Low Emissions Vehicle Data:

LEV_NMOG := $0.075 \cdot \frac{gm}{mi}$ LEV_NOx := $0.2 \cdot \frac{gm}{mi}$

LEV_CO := $3.4 \cdot \frac{gm}{mi}$ LEV_HCHO := $0.015 \cdot \frac{gm}{mi}$

LEV_HC := LEV_NMOG + LEV_HCHO

LEV_HC = $0.09 \frac{gm}{mi}$

Ultra Low Emissions Vehicle Data:

$$ULEV\_NMOG := 0.04 \cdot \frac{gm}{mi} \qquad ULEV\_NOx := 0.2 \cdot \frac{gm}{mi}$$

$$ULEV\_CO := 1.7 \cdot \frac{gm}{mi} \qquad ULEV\_HCHO := 0.008 \cdot \frac{gm}{mi}$$

$$ULEV\_HC := ULEV\_NMOG + ULEV\_HCHO$$

$$ULEV\_HC = 0.048 \frac{gm}{mi}$$

Super Low Emissions Vehicle Data:

$$SLEV\_CO := 1.0 \cdot \frac{gm}{mi} \qquad SLEV\_HC := 0.01 \cdot \frac{gm}{mi} \qquad SLEV\_NOx := 0.02 \cdot \frac{gm}{mi}$$

Zero Emissions Vehicle Data:

$$ZEV\_CO := 0 \cdot \frac{gm}{mi} \qquad ZEV\_HC := 0 \cdot \frac{gm}{mi} \qquad ZEV\_NOx := 0 \cdot \frac{gm}{mi}$$

Tier 1 Emissions Data:

$$T1\_CO := 4.2 \cdot \frac{gm}{mi} \qquad T1\_HC := 0.31 \cdot \frac{gm}{mi} \qquad T1\_NOx := 0.6 \cdot \frac{gm}{mi}$$

Tabulated Vehicle Distribution for New Vehicles:

$$SUV\_ZEV\_percentage := \frac{0.21}{100} \qquad LMM\_ZEV\_percentage := 0$$

$$SUV\_SLEV\_percentage := \frac{0}{100} \qquad LMM\_SLEV\_percentage := \frac{0}{100}$$

$$SUV\_ULEV\_percentage := \frac{4.5}{100} \qquad LMM\_ULEV\_percentage := \frac{19.13}{100}$$

$$SUV\_LEV\_percentage := \frac{51.82}{100} \qquad LMM\_LEV\_percentage := \frac{70.40}{100}$$

$$SUV\_TLEV\_percentage := \frac{1.5}{100} \qquad LMM\_TLEV\_percentage := \frac{7.94}{100}$$

$$SUV\_T1\_percentage := \frac{41.11}{100} \qquad LMM\_T1\_percentage := \frac{2.17}{100}$$

$$SmC\_ZEV\_percentage := \frac{0.26}{100} \qquad SmC\_LEV\_percentage := \frac{65.17}{100}$$

$$SmC\_SLEV\_percentage := \frac{0}{100} \qquad SmC\_TLEV\_percentage := \frac{9.5}{100}$$

$$SmC\_ULEV\_percentage := \frac{15.04}{100} \qquad SmC\_T1\_percentage := \frac{8.97}{100}$$

Percentages of Each New Vehicle Type Observed on the Road:

SmC_on_road := .2395 LMM_on_road := .5418

SUV_on_road := .2187

Equations:

Number_of_Vehicles := 1.0·Worcester_population·Vehicles_per_person

Number_of_Vehicles = 201371

$$\text{Commuter\_miles} := (\text{Travel\_distance})\cdot\left(\frac{2}{\text{day}}\right)\cdot(\text{Work\_days})\cdot(\text{Number\_of\_Vehicles})$$

Commuter_miles = 0.736 billion_miles driven per year

$$\text{Avg\_commuter\_miles} := \frac{\text{Commuter\_miles}}{\text{Number\_of\_Vehicles}} \qquad \text{Avg\_commuter\_miles} = 3.654\times 10^{3}\ \frac{\text{mi}}{\text{per vehicle driven per year}}$$

$$\text{Weekend\_miles} := \left(\frac{\text{Travel\_distance}}{2}\right)\cdot\left(\frac{2}{\text{day}}\right)\cdot(\text{Week\_ends})\cdot(\text{Number\_of\_Vehicles})$$

Weekend_miles = 146.598 millionmilesriven per year

$$\text{Avg\_weekend\_miles} := \frac{\text{Weekend\_miles}}{\text{Number\_of\_Vehicles}} \qquad \text{Avg\_weekend\_miles} = 728\ \frac{\text{mi}}{\text{per vehicle driven per year}}$$

Total_Worcester_miles := Weekend_miles + Commuter_miles Total_Worcester_miles = 0.882 billion_miles driven per year

Emissions Due to New SUV's

$$\text{SUV}_{\text{NOx}} := V_{9602}\cdot\left[\begin{array}{l}(\text{Total\_Worcester\_miles})\cdot(\text{SUV\_on\_road})\cdot(\text{SUV\_ZEV\_percentage})\cdot(\text{ZEV\_NOx})\ \ldots\\ +(\text{Total\_Worcester\_miles})\cdot(\text{SUV\_on\_road})\cdot(\text{SUV\_SLEV\_percentage})\cdot(\text{SLEV\_NOx})\ \ldots\\ +(\text{Total\_Worcester\_miles})\cdot(\text{SUV\_on\_road})\cdot(\text{SUV\_T1\_percentage})\cdot(\text{T1\_NOx})\ \ldots\\ +(\text{Total\_Worcester\_miles})\cdot(\text{SUV\_on\_road})\cdot(\text{SUV\_TLEV\_percentage})\cdot(\text{TLEV\_NOx})\ \ldots\\ +(\text{Total\_Worcester\_miles})\cdot(\text{SUV\_on\_road})\cdot(\text{SUV\_LEV\_percentage})\cdot(\text{LEV\_NOx})\ \ldots\\ +(\text{Total\_Worcester\_miles})\cdot(\text{SUV\_on\_road})\cdot(\text{SUV\_ULEV\_percentage})\cdot(\text{ULEV\_NOx})\end{array}\right]$$

$$\text{SUV}_{\text{NOx}} = 2.855\times 10^{7}\ \text{gm}$$

$$\text{SUV}_{\text{HC}} := V_{9602}\cdot\left[\begin{array}{l}(\text{Total\_Worcester\_miles})\cdot(\text{SUV\_on\_road})\cdot(\text{SUV\_ZEV\_percentage})\cdot(\text{ZEV\_HC})\ \ldots\\ +(\text{Total\_Worcester\_miles})\cdot(\text{SUV\_on\_road})\cdot(\text{SUV\_SLEV\_percentage})\cdot(\text{SLEV\_HC})\ \ldots\\ +(\text{Total\_Worcester\_miles})\cdot(\text{SUV\_on\_road})\cdot(\text{SUV\_T1\_percentage})\cdot(\text{T1\_HC})\ \ldots\\ +(\text{Total\_Worcester\_miles})\cdot(\text{SUV\_on\_road})\cdot(\text{SUV\_TLEV\_percentage})\cdot(\text{TLEV\_HC})\ \ldots\\ +(\text{Total\_Worcester\_miles})\cdot(\text{SUV\_on\_road})\cdot(\text{SUV\_LEV\_percentage})\cdot(\text{LEV\_HC})\ \ldots\\ +(\text{Total\_Worcester\_miles})\cdot(\text{SUV\_on\_road})\cdot(\text{SUV\_ULEV\_percentage})\cdot(\text{ULEV\_HC})\end{array}\right]$$

$$\text{SUV}_{\text{HC}} = 1.394\times 10^{7}\ \text{gm}$$

$$SUV_{CO} := V_{9602} \cdot \left[\begin{array}{l} (Total\_Worcester\_miles) \cdot (SUV\_on\_road) \cdot (SUV\_ZEV\_percentage) \cdot (ZEV\_CO) \ldots \\ + (Total\_Worcester\_miles) \cdot (SUV\_on\_road) \cdot (SUV\_SLEV\_percentage) \cdot (SLEV\_CO) \ldots \\ + (Total\_Worcester\_miles) \cdot (SUV\_on\_road) \cdot (SUV\_T1\_percentage) \cdot (T1\_CO) \ldots \\ + (Total\_Worcester\_miles) \cdot (SUV\_on\_road) \cdot (SUV\_TLEV\_percentage) \cdot (TLEV\_CO) \ldots \\ + (Total\_Worcester\_miles) \cdot (SUV\_on\_road) \cdot (SUV\_LEV\_percentage) \cdot (LEV\_CO) \ldots \\ + (Total\_Worcester\_miles) \cdot (SUV\_on\_road) \cdot (SUV\_ULEV\_percentage) \cdot (ULEV\_CO) \end{array} \right]$$

$$SUV_{CO} = 2.826 \times 10^{8}\ gm$$

Emissions Due to New Small Cars

$$SmC_{NOx} := V_{9602} \cdot \left[\begin{array}{l} (Total\_Worcester\_miles) \cdot (SmC\_on\_road) \cdot (SmC\_ZEV\_percentage) \cdot (ZEV\_NOx) \ldots \\ + (Total\_Worcester\_miles) \cdot (SmC\_on\_road) \cdot (SmC\_SLEV\_percentage) \cdot (SLEV\_NOx) \ldots \\ + (Total\_Worcester\_miles) \cdot (SmC\_on\_road) \cdot (SmC\_T1\_percentage) \cdot (T1\_NOx) \ldots \\ + (Total\_Worcester\_miles) \cdot (SmC\_on\_road) \cdot (SmC\_TLEV\_percentage) \cdot (TLEV\_NOx) \ldots \\ + (Total\_Worcester\_miles) \cdot (SmC\_on\_road) \cdot (SmC\_LEV\_percentage) \cdot (LEV\_NOx) \ldots \\ + (Total\_Worcester\_miles) \cdot (SmC\_on\_road) \cdot (SmC\_ULEV\_percentage) \cdot (ULEV\_NOx) \end{array} \right]$$

$$SmC_{NOx} = 2.159 \times 10^{7}\ gm$$

$$SmC_{HC} := V_{9602} \cdot \left[\begin{array}{l} (Total\_Worcester\_miles) \cdot (SmC\_on\_road) \cdot (SmC\_ZEV\_percentage) \cdot (ZEV\_HC) \ldots \\ + (Total\_Worcester\_miles) \cdot (SmC\_on\_road) \cdot (SmC\_SLEV\_percentage) \cdot (SLEV\_HC) \ldots \\ + (Total\_Worcester\_miles) \cdot (SmC\_on\_road) \cdot (SmC\_T1\_percentage) \cdot (T1\_HC) \ldots \\ + (Total\_Worcester\_miles) \cdot (SmC\_on\_road) \cdot (SmC\_TLEV\_percentage) \cdot (TLEV\_HC) \ldots \\ + (Total\_Worcester\_miles) \cdot (SmC\_on\_road) \cdot (SmC\_LEV\_percentage) \cdot (LEV\_HC) \ldots \\ + (Total\_Worcester\_miles) \cdot (SmC\_on\_road) \cdot (SmC\_ULEV\_percentage) \cdot (ULEV\_HC) \end{array} \right]$$

$$SmC_{HC} = 9.156 \times 10^{6}\ gm$$

$$SmC_{CO} := V_{9602} \cdot \left[\begin{array}{l} (Total\_Worcester\_miles) \cdot (SmC\_on\_road) \cdot (SmC\_ZEV\_percentage) \cdot (ZEV\_CO) \ldots \\ + (Total\_Worcester\_miles) \cdot (SmC\_on\_road) \cdot (SmC\_SLEV\_percentage) \cdot (SLEV\_CO) \ldots \\ + (Total\_Worcester\_miles) \cdot (SmC\_on\_road) \cdot (SmC\_T1\_percentage) \cdot (T1\_CO) \ldots \\ + (Total\_Worcester\_miles) \cdot (SmC\_on\_road) \cdot (SmC\_TLEV\_percentage) \cdot (TLEV\_CO) \ldots \\ + (Total\_Worcester\_miles) \cdot (SmC\_on\_road) \cdot (SmC\_LEV\_percentage) \cdot (LEV\_CO) \ldots \\ + (Total\_Worcester\_miles) \cdot (SmC\_on\_road) \cdot (SmC\_ULEV\_percentage) \cdot (ULEV\_CO) \end{array} \right]$$

$$SmC_{CO} = 2.714 \times 10^{8}\ gm$$

Emissions Due to New Large-Medium cars and Minivans

$$LMM_{NOx} := V_{9602}\cdot\begin{bmatrix} (Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_ZEV\_percentage)\cdot(ZEV\_NOx) \ldots \\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_SLEV\_percentage)\cdot(SLEV\_NOx) \ldots \\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_T1\_percentage)\cdot(T1\_NOx) \ldots \\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_TLEV\_percentage)\cdot(TLEV\_NOx) \ldots \\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_LEV\_percentage)\cdot(LEV\_NOx) \ldots \\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_ULEV\_percentage)\cdot(ULEV\_NOx) \end{bmatrix}$$

$$LMM_{NOx} = 4.334 \times 10^{7}\ gm$$

$$LMM_{HC} := V_{9602}\cdot\begin{bmatrix} (Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_ZEV\_percentage)\cdot(ZEV\_HC) \ldots \\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_SLEV\_percentage)\cdot(SLEV\_HC) \ldots \\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_T1\_percentage)\cdot(T1\_HC) \ldots \\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_TLEV\_percentage)\cdot(TLEV\_HC) \ldots \\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_LEV\_percentage)\cdot(LEV\_HC) \ldots \\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_ULEV\_percentage)\cdot(ULEV\_HC) \end{bmatrix}$$

$$LMM_{HC} = 1.75 \times 10^{7}\ gm$$

$$LMM_{CO} := V_{9602}\cdot\begin{bmatrix} (Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_ZEV\_percentage)\cdot(ZEV\_CO) \ldots \\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_SLEV\_percentage)\cdot(SLEV\_CO) \ldots \\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_T1\_percentage)\cdot(T1\_CO) \ldots \\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_TLEV\_percentage)\cdot(TLEV\_CO) \ldots \\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_LEV\_percentage)\cdot(LEV\_CO) \ldots \\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_ULEV\_percentage)\cdot(ULEV\_CO) \end{bmatrix}$$

$$LMM_{CO} = 5.964 \times 10^{8}\ gm$$

Emissions Due to Vehicles manufactured 1995 or before:

Note: Prior to 1996 vehicles were generally classified as either Light Duty Vehicles (LDV) or Light Dut Trucks (LDT)

Recalculated Old Vehicle Distributions

$LDV_{old} := SmC_{old} + LMM_{old}$ $LDV_{old} = 0.8$

$LDT_{old} := SUV_{old}$ $LDT_{old} = 0.2$

x100 percent distribution

1992 to 1995 Emissions Data:

By 1992, all vehicles had to conform to the following Federal standard:

$LDV\_9295_{CO} := 3.4 \cdot \frac{gm}{mi}$ $LDV\_9295_{HC} := 0.41 \cdot \frac{gm}{mi}$ $LDV\_9295_{NOx} := 1.0 \cdot \frac{gm}{mi}$

$LDT\_9295_{CO} := 10 \cdot \frac{gm}{mi}$ $LDT\_9295_{HC} := 0.67 \cdot \frac{gm}{mi}$ $LDT\_9295_{NOx} := 1.2 \cdot \frac{gm}{mi}$

1982 - 1991 Emissions Data:

In this time frame, HC were not regulated. Instead Volatile Organic Compounds (VOC) were the standard, and will be considered nearly equivalent to HC's

Vehicles older than 1991 have reached their full usefull life of 10 yrs / 100,000 mi

$LDV\_8291_{CO} := 4.2 \cdot \frac{gm}{mi}$ $LDV\_8291_{VOC} := 0.80 \cdot \frac{gm}{mi}$ $LDV\_8291_{NOx} := 1.0 \frac{gm}{mi}$

$LDT\_8291_{CO} := \frac{10 \cdot 8 + 18}{9} \cdot \frac{gm}{mi}$ $LDT\_8291_{VOC} := 0.80 \cdot \frac{gm}{mi}$ $LDT\_8291_{NOx} := 1.2 \cdot \frac{gm}{mi}$

Pre 1982 Data:

$LDV\_P82_{CO} := \frac{23 \cdot 2 + 39 \cdot 3 + 15 \cdot 5}{10} \cdot \frac{gm}{mi}$ $LDV\_P82_{NOx} := \frac{3 \cdot 3 + 3.1 \cdot 2 + 2 \cdot 4 + 1 \cdot 2}{11} \cdot \frac{gm}{mi}$

$LDV\_P82_{VOC} := \frac{3.4 \cdot 3 + 1.5 \cdot 5 + 0.41 \cdot 2}{10} \cdot \frac{gm}{mi}$

$LDT\_P82_{CO} := \frac{39 \cdot 3 + 20 \cdot 5 + 18 \cdot 4}{12} \cdot \frac{gm}{mi}$ $LDT\_P82_{VOC} := \frac{3.4 \cdot 3 + 2 \cdot 4 + 1.7 \cdot 6}{13} \cdot \frac{gm}{mi}$

$LDT\_P82_{NOx} := \frac{3 \cdot 3 + 3.1 \cdot 4 + 2.3 \cdot 6}{13} \cdot \frac{gm}{mi}$

Emissions Calculations:

1992 - 1995

$LDV9295_{CO} := V_{9295} \cdot (Total\_Worcester\_miles) \cdot LDV\_9295_{CO} \cdot LDC\%$ $LDV9295_{CO} = 7.2 \times 10^{8}\ gm$

$LDT9295_{CO} := V_{9295} \cdot (Total\_Worcester\_miles) \cdot LDT\_9295_{CO} \cdot LDT\%$ $LDT9295_{CO} = 5.294 \times 10^{8}\ gm$

$LDV9295_{NOx} := V_{9295} \cdot (Total\_Worcester\_miles) \cdot LDV\_9295_{NOx} \cdot LDC\%$ $LDV9295_{NOx} = 2.118 \times 10^{8}\ gm$

$LDT9295_{NOx} := V_{9295} \cdot (Total\_Worcester\_miles) \cdot LDT\_9295_{NOx} \cdot LDT\%$ $LDT9295_{NOx} = 6.353 \times 10^{7}\ gm$

$LDV9295_{HC} := V_{9295} \cdot (Total\_Worcester\_miles) \cdot LDV\_9295_{HC} \cdot LDC\%$ $LDV9295_{HC} = 8.683 \times 10^{7}\ gm$

$LDT9295_{HC} := V_{9295} \cdot (Total\_Worcester\_miles) \cdot LDT\_9295_{HC} \cdot LDT\%$ $LDT9295_{HC} = 3.547 \times 10^{7}\ gm$

1982-1991

$LDV8291_{CO} := V_{8291} \cdot (Total\_Worcester\_miles) \cdot LDV\_8291_{CO} \cdot LDC\%$ $LDV8291_{CO} = 6.523 \times 10^{8}\ gm$

$LDT8291_{CO} := V_{8291} \cdot (Total\_Worcester\_miles) \cdot LDT\_8291_{CO} \cdot LDT\%$ $LDT8291_{CO} = 4.228 \times 10^{8}\ gm$

$LDV8291_{NOx} := V_{8291} \cdot (Total\_Worcester\_miles) \cdot LDV\_8291_{NOx} \cdot LDC\%$ $LDV8291_{NOx} = 1.553 \times 10^{8}\ gm$

$LDT8291_{NOx} := V_{8291} \cdot (Total\_Worcester\_miles) \cdot LDT\_8291_{NOx} \cdot LDT\%$ $LDT8291_{NOx} = 4.659 \times 10^{7}\ gm$

$LDV8291_{VOC} := V_{8291} \cdot (Total\_Worcester\_miles) \cdot LDV\_8291_{VOC} \cdot LDC\%$ $LDV8291_{VOC} = 1.242 \times 10^{8}\ gm$

$LDT8291_{VOC} := V_{8291} \cdot (Total\_Worcester\_miles) \cdot LDT\_8291_{VOC} \cdot LDT\%$ $LDT8291_{VOC} = 3.106 \times 10^{7}\ gm$

Pre 1982

$LDVP82_{CO} := V_{P82} \cdot (Total\_Worcester\_miles) \cdot LDV\_P82_{CO} \cdot LDC\%$ $LDVP82_{CO} = 5.04 \times 10^{8}\ gm$

$LDTP82_{CO} := V_{P82} \cdot (Total\_Worcester\_miles) \cdot LDT\_P82_{CO} \cdot LDT\%$ $LDTP82_{CO} = 1.275 \times 10^{8}\ gm$

$LDVP82_{NOx} := V_{P82} \cdot (Total\_Worcester\_miles) \cdot LDV\_P82_{NOx} \cdot LDC\%$ $LDVP82_{NOx} = 4.852 \times 10^{7}\ gm$

$LDTP82_{NOx} := V_{P82} \cdot (Total\_Worcester\_miles) \cdot LDT\_P82_{NOx} \cdot LDT\%$ $LDTP82_{NOx} = 1.434 \times 10^{7}\ gm$

$LDVP82_{VOC} := V_{P82} \cdot (Total\_Worcester\_miles) \cdot LDV\_P82_{VOC} \cdot LDC\%$ $LDVP82_{VOC} = 3.922 \times 10^{7}\ gm$

$LDTP82_{VOC} := V_{P82} \cdot (Total\_Worcester\_miles) \cdot LDT\_P82_{VOC} \cdot LDT\%$ $LDTP82_{VOC} = 1.157 \times 10^{7}\ gm$

Total Emissions of New Vehicles, (English Tons):

Carbon Monoxide:

$$CO_{new} := LMM_{CO} + SmC_{CO} + SUV_{CO} \qquad CO_{new} = 1268.1\,ton$$

$LMM_{CO} = 657.4\,ton$

$SmC_{CO} = 299.2\,ton$

$SUV_{CO} = 311.5\,ton$

Nitrous Oxides:

$$NOx_{new} := LMM_{NOx} + SmC_{NOx} + SUV_{NOx} \qquad NOx_{new} = 103\,ton$$

$LMM_{NOx} = 47.8\,ton$

$SmC_{NOx} = 23.8\,ton$

$SUV_{NOx} = 31.5\,ton$

Hydocarbons:

$$HC_{new} := LMM_{HC} + SmC_{HC} + SUV_{HC} \qquad HC_{new} = 44.7\,ton$$

$LMM_{HC} = 19.3\,ton$

$SmC_{HC} = 10.1\,ton$

$SUV_{HC} = 15.4\,ton$

Total Emissions:

$$Emissions_{new} := CO_{new} + NOx_{new} + HC_{new}$$

$$Emissions_{new} = 1415.9\,ton$$

Total Emissions of Older Vehicles, (English Tons):

Carbon Monoxide:

$LDV9295_{CO} = 793.7\,ton$ $LDV8291_{CO} = 719\,ton$ $LDVP82_{CO} = 555.6\,ton$

$LDT9295_{CO} = 583.6\,ton$ $LDT8291_{CO} = 466\,ton$ $LDTP82_{CO} = 140.6\,ton$

$$CO_{old} := LDV9295_{CO} + LDT9295_{CO} + LDV8291_{CO} + LDT8291_{CO} \cdots + LDVP82_{CO} + LDTP82_{CO}$$

Nitrous Oxides:

$LDV9295_{NOx} = 233.4\,ton$ $LDV8291_{NOx} = 171.2\,ton$ $LDVP82_{NOx} = 53.5\,ton$

$LDT9295_{NOx} = 70\,ton$ $LDT8291_{NOx} = 51.4\,ton$ $LDTP82_{NOx} = 15.8\,ton$

$$NOx_{old} := LDV9295_{NOx} + LDT9295_{NOx} + LDV8291_{NOx} + LDT8291_{NOx} \cdots + LDVP82_{NOx} + LDTP82_{NOx}$$

HydroCarbons and Volatile Organic Compounds:

$LDV9295_{HC} = 95.7\,ton$ $LDV8291_{VOC} = 137\,ton$ $LDVP82_{VOC} = 43.2\,ton$

$LDT9295_{HC} = 39.1\,ton$ $LDT8291_{VOC} = 34.2\,ton$ $LDTP82_{VOC} = 12.7\,ton$

$$HC_{old} := LDV9295_{HC} + LDT9295_{HC} + LDV8291_{VOC} + LDT8291_{VOC} \cdots + LDVP82_{VOC} + LDTP82_{VOC}$$

Totals for Older Vehicles:

$CO_{old} = 3258.5\,ton$ $NOx_{old} = 595.3\,ton$ $HC_{old} = 362\,ton$

$Emissions_{old} := CO_{old} + NOx_{old} + HC_{old}$

$Emissions_{old} = 4215.8\,ton$

Calculate emissions of a population of SLEV

$Number\_of\_SLEV := (0.10)\cdot\left(V\%_{new}\right)\cdot Worcester\_population\cdot Vehicles\_per\_person$

$Commuter\_miles_{SLEV} := (Travel\_distance)\cdot\left(\frac{2}{day}\right)\cdot(Work\_days)\cdot(Number\_of\_SLEV)$

$Commuter\_miles_{SLEV} = 0.033\,billion\_miles$ driven per year

$Avg\_commuter\_miles_{SLEV} := \frac{Commuter\_miles_{SLE}}{Number\_of\_SLEV}$ $Avg\_commuter\_miles_{SLEV} = 3.654\times10^{3}\,mi$ per vehicle driven per year

$Weekend\_miles_{SLEV} := \left(\frac{Travel\_distance}{2}\right)\cdot\left(\frac{2}{day}\right)\cdot(Week\_ends)\cdot(Number\_of\_SLEV)$

$Weekend\_miles_{SLEV} = 6.597\,million\_miles$ driven per year

$Avg\_weekend\_miles_{SLEV} := \frac{Weekend\_miles_{SLEV}}{Number\_of\_SLEV}$ $Avg\_weekend\_miles_{SLEV} = 728\,mi$ per venicle driven per year

$Total\_Worcester\_miles_{SLEV} := Weekend\_miles_{SLEV} + Commuter\_miles_{SLEV}$

$Total\_Worcester\_miles_{SLEV} = 0.04\,billion\_miles$ driven per year

$SLEV_{CO} := Total\_Worcester\_miles_{SLEV}\cdot SLEV\_CO$ $SLEV_{CO} = 43.771\,ton$

$SLEV_{HC} := Total\_Worcester\_miles_{SLEV}\cdot SLEV\_HC$ $SLEV_{HC} = 0.438\,ton$

$SLEV_{NOx} := Total\_Worcester\_miles_{SLEV}\cdot SLEV\_NOx$ $SLEV_{NOx} = 0.875\,ton$

$Total\_Emissions := Emissions_{new} + Emissions_{old} + SLEV_{CO} + SLEV_{HC} + SLEV_{NOx}$

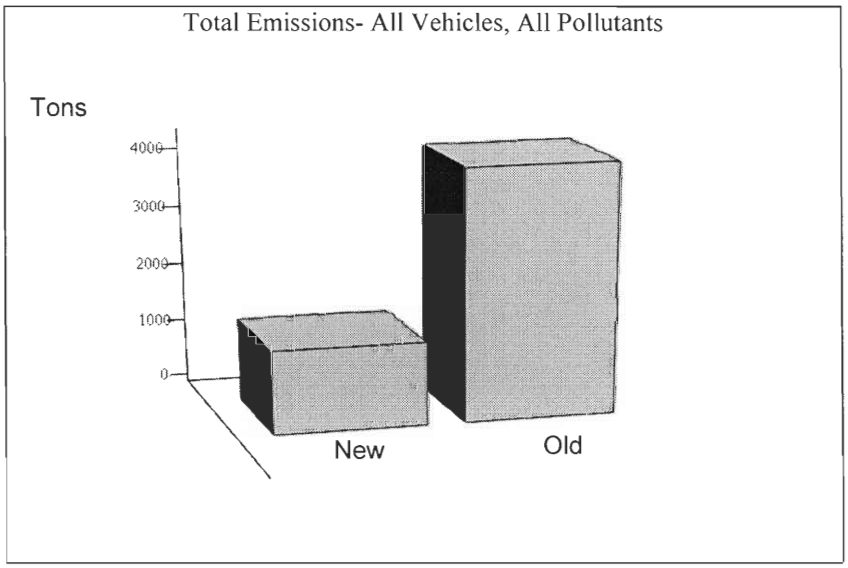
$Total\_Emissions = 5676.8\,ton$

$CO_{Tot} := SLEV_{CO} + CO_{old} + CO_{new}$ $CO_{Tot} = 4570.4\,ton$

$NOx_{Tot} := SLEV_{NOx} + NOx_{old} + NOx_{new}$ $NOx_{Tot} = 699.2\,ton$

$HC_{Tot} := SLEV_{HC} + HC_{old} + HC_{new}$ $HC_{Tot} = 407.2\,ton$

$$Graph1 := \left(\frac{Emissions_{new}}{2000} \quad \frac{Emissions_{old}}{2000} \right)$$



Replacing 10% of all old Vehicles w/Hybrids

billion_miles := $10^9 \cdot mi$

million_miles := $10^6 \cdot mi$

Assumptions:

Vehicles traveling through Worcester Travel an average of 7 miles each

Travel_distance := $7 \cdot mi$

Work_days := $261 \cdot day$

Week_ends := $104 \cdot day$

City Data:

Worcester_population := 254900 people

Vehicles_per_person := 0.79

Percentages of Vehicle Types:

Newer Vehicles:

SUV := 0.275 SmC := 0.21 LMM := 0.51

Older Vehicles:

SUV_{old} := 0.20 SmC_{old} := 0.20 LMM_{old} := 0.60 LDT% := SUV_{old}

LDC% := $SmC_{old} + LMM_{old}$

Age distribution of Vehicles on the Roads:

1996 - 2002 V_{9602} := 0.45

1992 - 1995 $V_{9295} := 0.30 \cdot (0.90)$

1982 - 1991 $V_{8291} := 0.22(0.90)$

Pre 1982 $V_{P82} := 0.03 \cdot (0.90)$

$V\%_{old}$:= 0.55 55% of all worcester vehicles are "old"

Transitional Low Emissions Vehicle Data:

TLEV_NMOG := $0.125 \cdot \frac{gm}{mi}$ TLEV_NOx := $0.4 \cdot \frac{gm}{mi}$

TLEV_CO := $3.4 \cdot \frac{gm}{mi}$ TLEV_HCHO := $0.015 \cdot \frac{gm}{mi}$

TLEV HC := TLEV NMOG + TLEV_HCHO

TLEV_HC = $0.14 \frac{gm}{mi}$

Low Emissions Vehicle Data:

LEV_NMOG := $0.075 \cdot \frac{gm}{mi}$ LEV_NOx := $0.2 \cdot \frac{gm}{mi}$

LEV_CO := $3.4 \cdot \frac{gm}{mi}$ LEV_HCHO := $0.015 \cdot \frac{gm}{mi}$

LEV_HC := LEV_NMOG + LEV_HCHO

LEV_HC = $0.09 \frac{gm}{mi}$

Ultra Low Emissions Vehicle Data:

$$ULEV\_NMOG := 0.04 \cdot \frac{gm}{mi} \qquad ULEV\_NOx := 0.2 \cdot \frac{gm}{mi}$$

$$ULEV\_CO := 1.7 \cdot \frac{gm}{mi} \qquad ULEV\_HCHO := 0.008 \cdot \frac{gm}{mi}$$

$$ULEV\_HC := ULEV\_NMOG + ULEV\_HCHO$$

$$ULEV\_HC = 0.048 \frac{gm}{mi}$$

Super Low Emissions Vehicle Data:

$$SLEV\_CO := 1.0 \cdot \frac{gm}{mi} \qquad SLEV\_HC := 0.01 \cdot \frac{gm}{mi} \qquad SLEV\_NOx := 0.02 \cdot \frac{gm}{mi}$$

Zero Emissions Vehicle Data:

$$ZEV\_CO := 0 \cdot \frac{gm}{mi} \qquad ZEV\_HC := 0 \cdot \frac{gm}{mi} \qquad ZEV\_NOx := 0 \cdot \frac{gm}{mi}$$

Tier 1 Emissions Data:

$$T1\_CO := 4.2 \cdot \frac{gm}{mi} \qquad T1\_HC := 0.31 \cdot \frac{gm}{mi} \qquad T1\_NOx := 0.6 \cdot \frac{gm}{mi}$$

Tabulated Vehicle Distribution for New Vehicles:

$$SUV\_ZEV\_percentage := \frac{0.21}{100} \qquad LMM\_ZEV\_percentage := 0$$

$$SUV\_SLEV\_percentage := \frac{0}{100} \qquad LMM\_SLEV\_percentage := \frac{0}{100}$$

$$SUV\_ULEV\_percentage := \frac{4.5}{100} \qquad LMM\_ULEV\_percentage := \frac{19.13}{100}$$

$$SUV\_LEV\_percentage := \frac{51.82}{100} \qquad LMM\_LEV\_percentage := \frac{70.40}{100}$$

$$SUV\_TLEV\_percentage := \frac{1.5}{100} \qquad LMM\_TLEV\_percentage := \frac{7.94}{100}$$

$$SUV\_T1\_percentage := \frac{41.11}{100} \qquad LMM\_T1\_percentage := \frac{2.17}{100}$$

$$SmC\_ZEV\_percentage := \frac{0.26}{100} \qquad SmC\_LEV\_percentage := \frac{65.17}{100}$$

$$SmC\_SLEV\_percentage := \frac{0}{100} \qquad SmC\_TLEV\_percentage := \frac{9.5}{100}$$

$$SmC\_ULEV\_percentage := \frac{15.04}{100} \qquad SmC\_T1\_percentage := \frac{8.97}{100}$$

Percentages of Each New Vehicle Type Observed on the Road:

SmC_on_road := .2395 LMM_on_road := .5418

SUV_on_road := .2187

Equations:

Number_of_Vehicles := 1.0·Worcester_population·Vehicles_per_person

Number_of_Vehicles = 201371

$$\text{Commuter\_miles} := (\text{Travel\_distance})\cdot\left(\frac{2}{\text{day}}\right)\cdot(\text{Work\_days})\cdot(\text{Number\_of\_Vehicles})$$

Commuter_miles = 0.736 billion_miles driven per year

$$\text{Avg\_commuter\_miles} := \frac{\text{Commuter\_miles}}{\text{Number\_of\_Vehicles}} \qquad \text{Avg\_commuter\_miles} = 3.654\times 10^{3}\ \frac{\text{mi}}{\text{per vehicle driven per year}}$$

$$\text{Weekend\_miles} := \left(\frac{\text{Travel\_distance}}{2}\right)\cdot\left(\frac{2}{\text{day}}\right)\cdot(\text{Week\_ends})\cdot(\text{Number\_of\_Vehicles})$$

Weekend_miles = 146.598 million_milesriven per year

$$\text{Avg\_weekend\_miles} := \frac{\text{Weekend\_miles}}{\text{Number\_of\_Vehicles}} \qquad \text{Avg\_weekend\_miles} = 728\ \frac{\text{mi}}{\text{per vehicle driven per year}}$$

Total_Worcester_miles := Weekend_miles + Commuter_miles Total_Worcester_miles = 0.882 billion_miles driven per year

Emissions Due to New SUV's

$$\text{SUV}_{\text{NOx}} := V_{9602}\cdot\left[\begin{array}{l}(\text{Total\_Worcester\_miles})\cdot(\text{SUV\_on\_road})\cdot(\text{SUV\_ZEV\_percentage})\cdot(\text{ZEV\_NOx})\ \ldots\\ +(\text{Total\_Worcester\_miles})\cdot(\text{SUV\_on\_road})\cdot(\text{SUV\_SLEV\_percentage})\cdot(\text{SLEV\_NOx})\ \ldots\\ +(\text{Total\_Worcester\_miles})\cdot(\text{SUV\_on\_road})\cdot(\text{SUV\_T1\_percentage})\cdot(\text{T1\_NOx})\ \ldots\\ +(\text{Total\_Worcester\_miles})\cdot(\text{SUV\_on\_road})\cdot(\text{SUV\_TLEV\_percentage})\cdot(\text{TLEV\_NOx})\ \ldots\\ +(\text{Total\_Worcester\_miles})\cdot(\text{SUV\_on\_road})\cdot(\text{SUV\_LEV\_percentage})\cdot(\text{LEV\_NOx})\ \ldots\\ +(\text{Total\_Worcester\_miles})\cdot(\text{SUV\_on\_road})\cdot(\text{SUV\_ULEV\_percentage})\cdot(\text{ULEV\_NOx})\end{array}\right]$$

$$\text{SUV}_{\text{NOx}} = 3.172\times 10^{7}\ \text{gm}$$

$$\text{SUV}_{\text{HC}} := V_{9602}\cdot\left[\begin{array}{l}(\text{Total\_Worcester\_miles})\cdot(\text{SUV\_on\_road})\cdot(\text{SUV\_ZEV\_percentage})\cdot(\text{ZEV\_HC})\ \ldots\\ +(\text{Total\_Worcester\_miles})\cdot(\text{SUV\_on\_road})\cdot(\text{SUV\_SLEV\_percentage})\cdot(\text{SLEV\_HC})\ \ldots\\ +(\text{Total\_Worcester\_miles})\cdot(\text{SUV\_on\_road})\cdot(\text{SUV\_T1\_percentage})\cdot(\text{T1\_HC})\ \ldots\\ +(\text{Total\_Worcester\_miles})\cdot(\text{SUV\_on\_road})\cdot(\text{SUV\_TLEV\_percentage})\cdot(\text{TLEV\_HC})\ \ldots\\ +(\text{Total\_Worcester\_miles})\cdot(\text{SUV\_on\_road})\cdot(\text{SUV\_LEV\_percentage})\cdot(\text{LEV\_HC})\ \ldots\\ +(\text{Total\_Worcester\_miles})\cdot(\text{SUV\_on\_road})\cdot(\text{SUV\_ULEV\_percentage})\cdot(\text{ULEV\_HC})\end{array}\right]$$

$$\text{SUV}_{\text{HC}} = 1.549\times 10^{7}\ \text{gm}$$

$$SUV_{CO} := V_{9602}\cdot\left[\begin{array}{l}(Total\_Worcester\_miles)\cdot(SUV\_on\_road)\cdot(SUV\_ZEV\_percentage)\cdot(ZEV\_CO) \ldots \\ +(Total\_Worcester\_miles)\cdot(SUV\_on\_road)\cdot(SUV\_SLEV\_percentage)\cdot(SLEV\_CO) \ldots \\ +(Total\_Worcester\_miles)\cdot(SUV\_on\_road)\cdot(SUV\_T1\_percentage)\cdot(T1\_CO) \ldots \\ +(Total\_Worcester\_miles)\cdot(SUV\_on\_road)\cdot(SUV\_TLEV\_percentage)\cdot(TLEV\_CO) \ldots \\ +(Total\_Worcester\_miles)\cdot(SUV\_on\_road)\cdot(SUV\_LEV\_percentage)\cdot(LEV\_CO) \ldots \\ +(Total\_Worcester\_miles)\cdot(SUV\_on\_road)\cdot(SUV\_ULEV\_percentage)\cdot(ULEV\_CO)\end{array}\right]$$

$$SUV_{CO} = 3.14 \times 10^{8}\ gm$$

Emissions Due to New Small Cars

$$SmC_{NOx} := V_{9602}\cdot\left[\begin{array}{l}(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_ZEV\_percentage)\cdot(ZEV\_NOx) \ldots \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_SLEV\_percentage)\cdot(SLEV\_NOx) \ldots \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_T1\_percentage)\cdot(T1\_NOx) \ldots \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_TLEV\_percentage)\cdot(TLEV\_NOx) \ldots \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_LEV\_percentage)\cdot(LEV\_NOx) \ldots \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_ULEV\_percentage)\cdot(ULEV\_NOx)\end{array}\right]$$

$$SmC_{NOx} = 2.399 \times 10^{7}\ gm$$

$$SmC_{HC} := V_{9602}\cdot\left[\begin{array}{l}(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_ZEV\_percentage)\cdot(ZEV\_HC) \ldots \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_SLEV\_percentage)\cdot(SLEV\_HC) \ldots \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_T1\_percentage)\cdot(T1\_HC) \ldots \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_TLEV\_percentage)\cdot(TLEV\_HC) \ldots \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_LEV\_percentage)\cdot(LEV\_HC) \ldots \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_ULEV\_percentage)\cdot(ULEV\_HC)\end{array}\right]$$

$$SmC_{HC} = 1.017 \times 10^{7}\ gm$$

$$SmC_{CO} := V_{9602}\cdot\left[\begin{array}{l}(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_ZEV\_percentage)\cdot(ZEV\_CO) \ldots \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_SLEV\_percentage)\cdot(SLEV\_CO) \ldots \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_T1\_percentage)\cdot(T1\_CO) \ldots \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_TLEV\_percentage)\cdot(TLEV\_CO) \ldots \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_LEV\_percentage)\cdot(LEV\_CO) \ldots \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_ULEV\_percentage)\cdot(ULEV\_CO)\end{array}\right]$$

$$SmC_{CO} = 3.016 \times 10^{8}\ gm$$

Emissions Due to New Large-Medium cars and Minivans

$$LMM_{NOx} := V_{9602}\cdot\left[\begin{array}{l}(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_ZEV\_percentage)\cdot(ZEV\_NOx)\ ...\\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_SLEV\_percentage)\cdot(SLEV\_NOx)\ ...\\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_T1\_percentage)\cdot(T1\_NOx)\ ...\\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_TLEV\_percentage)\cdot(TLEV\_NOx)\ ...\\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_LEV\_percentage)\cdot(LEV\_NOx)\ ...\\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_ULEV\_percentage)\cdot(ULEV\_NOx)\end{array}\right]$$

$$LMM_{NOx} = 4.816\times 10^{7}\ gm$$

$$LMM_{HC} := V_{9602}\cdot\left[\begin{array}{l}(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_ZEV\_percentage)\cdot(ZEV\_HC)\ ...\\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_SLEV\_percentage)\cdot(SLEV\_HC)\ ...\\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_T1\_percentage)\cdot(T1\_HC)\ ...\\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_TLEV\_percentage)\cdot(TLEV\_HC)\ ...\\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_LEV\_percentage)\cdot(LEV\_HC)\ ...\\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_ULEV\_percentage)\cdot(ULEV\_HC)\end{array}\right]$$

$$LMM_{HC} = 1.945\times 10^{7}\ gm$$

$$LMM_{CO} := V_{9602}\cdot\left[\begin{array}{l}(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_ZEV\_percentage)\cdot(ZEV\_CO)\ ...\\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_SLEV\_percentage)\cdot(SLEV\_CO)\ ...\\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_T1\_percentage)\cdot(T1\_CO)\ ...\\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_TLEV\_percentage)\cdot(TLEV\_CO)\ ...\\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_LEV\_percentage)\cdot(LEV\_CO)\ ...\\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_ULEV\_percentage)\cdot(ULEV\_CO)\end{array}\right]$$

$$LMM_{CO} = 6.626\times 10^{8}\ gm$$

Emissions Due to Vehicles manufactured 1995 or before:

Note: Prior to 1996 vehicles were generally classified as either Light Duty Vehicles (LDV) or Light Dut Trucks (LDT)

Recalculated Old Vehicle Distributions

$LDV_{old} := SmC_{old} + LMM_{old}$ $\quad LDV_{old} = 0.8$

$LDT_{old} := SUV_{old}$ $\quad LDT_{old} = 0.2$

x100 percent distribution

1992 to 1995 Emissions Data:

By 1992, all vehicles had to conform to the following Federal standard:

$LDV\_9295_{CO} := 3.4 \cdot \frac{gm}{mi}$ $\quad LDV\_9295_{HC} := 0.41 \cdot \frac{gm}{mi}$ $\quad LDV\_9295_{NOx} := 1.0 \cdot \frac{gm}{mi}$

$LDT\_9295_{CO} := 10 \cdot \frac{gm}{mi}$ $\quad LDT\_9295_{HC} := 0.67 \cdot \frac{gm}{mi}$ $\quad LDT\_9295_{NOx} := 1.2 \cdot \frac{gm}{mi}$

1982 - 1991 Emissions Data:

In this time frame, HC were not regulated. Instead Volatile Organic Compounds (VOC) were the standard, and will be considered nearly equivalent to HC's

Vehicles older than 1991 have reached their full usefull life of 10 yrs / 100,000 mi

$LDV\_8291_{CO} := 4.2 \cdot \frac{gm}{mi}$ $\quad LDV\_8291_{VOC} := 0.80 \cdot \frac{gm}{mi}$ $\quad LDV\_8291_{NOx} := 1.0 \frac{gm}{mi}$

$LDT\_8291_{CO} := \frac{10 \cdot 8 + 18}{9} \cdot \frac{gm}{mi}$ $\quad LDT\_8291_{VOC} := 0.80 \cdot \frac{gm}{mi}$ $\quad LDT\_8291_{NOx} := 1.2 \cdot \frac{gm}{mi}$

Pre 1982 Data:

$LDV\_P82_{CO} := \frac{23 \cdot 2 + 39 \cdot 3 + 15 \cdot 5}{10} \cdot \frac{gm}{mi}$ $\quad LDV\_P82_{NOx} := \frac{3 \cdot 3 + 3.1 \cdot 2 + 2 \cdot 4 + 1 \cdot 2}{11} \cdot \frac{gm}{mi}$

$LDV\_P82_{VOC} := \frac{3.4 \cdot 3 + 1.5 \cdot 5 + 0.41 \cdot 2}{10} \cdot \frac{gm}{mi}$

$LDT\_P82_{CO} := \frac{39 \cdot 3 + 20 \cdot 5 + 18 \cdot 4}{12} \cdot \frac{gm}{mi}$ $\quad LDT\_P82_{VOC} := \frac{3.4 \cdot 3 + 2 \cdot 4 + 1.7 \cdot 6}{13} \cdot \frac{gm}{mi}$

$LDT\_P82_{NOx} := \frac{3 \cdot 3 + 3.1 \cdot 4 + 2.3 \cdot 6}{13} \cdot \frac{gm}{mi}$

Emissions Calculations:

1992 - 1995

$LDV9295_{CO} := V_{9295} \cdot (Total\_Worcester\_miles) \cdot LDV\_9295_{CO} \cdot LDC\%$ $LDV9295_{CO} = 6.48 \times 10^{8}\ gm$

$LDT9295_{CO} := V_{9295} \cdot (Total\_Worcester\_miles) \cdot LDT\_9295_{CO} \cdot LDT\%$ $LDT9295_{CO} = 4.765 \times 10^{8}\ gm$

$LDV9295_{NOx} := V_{9295} \cdot (Total\_Worcester\_miles) \cdot LDV\_9295_{NOx} \cdot LDC\%$ $LDV9295_{NOx} = 1.906 \times 10^{8}\ gm$

$LDT9295_{NOx} := V_{9295} \cdot (Total\_Worcester\_miles) \cdot LDT\_9295_{NOx} \cdot LDT\%$ $LDT9295_{NOx} = 5.718 \times 10^{7}\ gm$

$LDV9295_{HC} := V_{9295} \cdot (Total\_Worcester\_miles) \cdot LDV\_9295_{HC} \cdot LDC\%$ $LDV9295_{HC} = 7.815 \times 10^{7}\ gm$

$LDT9295_{HC} := V_{9295} \cdot (Total\_Worcester\_miles) \cdot LDT\_9295_{HC} \cdot LDT\%$ $LDT9295_{HC} = 3.193 \times 10^{7}\ gm$

1982-1991

$LDV8291_{CO} := V_{8291} \cdot (Total\_Worcester\_miles) \cdot LDV\_8291_{CO} \cdot LDC\%$ $LDV8291_{CO} = 5.87 \times 10^{8}\ gm$

$LDT8291_{CO} := V_{8291} \cdot (Total\_Worcester\_miles) \cdot LDT\_8291_{CO} \cdot LDT\%$ $LDT8291_{CO} = 3.805 \times 10^{8}\ gm$

$LDV8291_{NOx} := V_{8291} \cdot (Total\_Worcester\_miles) \cdot LDV\_8291_{NOx} \cdot LDC\%$ $LDV8291_{NOx} = 1.398 \times 10^{8}\ gm$

$LDT8291_{NOx} := V_{8291} \cdot (Total\_Worcester\_miles) \cdot LDT\_8291_{NOx} \cdot LDT\%$ $LDT8291_{NOx} = 4.193 \times 10^{7}\ gm$

$LDV8291_{VOC} := V_{8291} \cdot (Total\_Worcester\_miles) \cdot LDV\_8291_{VOC} \cdot LDC\%$ $LDV8291_{VOC} = 1.118 \times 10^{8}\ gm$

$LDT8291_{VOC} := V_{8291} \cdot (Total\_Worcester\_miles) \cdot LDT\_8291_{VOC} \cdot LDT\%$ $LDT8291_{VOC} = 2.795 \times 10^{7}\ gm$

Pre 1982

$LDVP82_{CO} := V_{P82} \cdot (Total\_Worcester\_miles) \cdot LDV\_P82_{CO} \cdot LDC\%$ $LDVP82_{CO} = 4.536 \times 10^{8}\ gm$

$LDTP82_{CO} := V_{P82} \cdot (Total\_Worcester\_miles) \cdot LDT\_P82_{CO} \cdot LDT\%$ $LDTP82_{CO} = 1.148 \times 10^{8}\ gm$

$LDVP82_{NOx} := V_{P82} \cdot (Total\_Worcester\_miles) \cdot LDV\_P82_{NOx} \cdot LDC\%$ $LDVP82_{NOx} = 4.366 \times 10^{7}\ gm$

$LDTP82_{NOx} := V_{P82} \cdot (Total\_Worcester\_miles) \cdot LDT\_P82_{NOx} \cdot LDT\%$ $LDTP82_{NOx} = 1.29 \times 10^{7}\ gm$

$LDVP82_{VOC} := V_{P82} \cdot (Total\_Worcester\_miles) \cdot LDV\_P82_{VOC} \cdot LDC\%$ $LDVP82_{VOC} = 3.53 \times 10^{7}\ gm$

$LDTP82_{VOC} := V_{P82} \cdot (Total\_Worcester\_miles) \cdot LDT\_P82_{VOC} \cdot LDT\%$ $LDTP82_{VOC} = 1.041 \times 10^{7}\ gm$

Total Emissions of New Vehicles, (English Tons):

Carbon Monoxide:

$$CO_{new} := LMM_{CO} + SmC_{CO} + SUV_{CO}$$

$$CO_{new} = 1409\,ton$$

$LMM_{CO} = 730.4\,ton$

$SmC_{CO} = 332.4\,ton$

$SUV_{CO} = 346.1\,ton$

Nitrous Oxides:

$$NOx_{new} := LMM_{NOx} + SmC_{NOx} + SUV_{NOx}$$

$$NOx_{new} = 114.5\,ton$$

$LMM_{NOx} = 53.1\,ton$

$SmC_{NOx} = 26.4\,ton$

$SUV_{NOx} = 35\,ton$

Hydocarbons:

$$HC_{new} := LMM_{HC} + SmC_{HC} + SUV_{HC}$$

$$HC_{new} = 49.7\,ton$$

$LMM_{HC} = 21.4\,ton$

$SmC_{HC} = 11.2\,ton$

$SUV_{HC} = 17.1\,ton$

Total Emissions:

$$Emissions_{new} := CO_{new} + NOx_{new} + HC_{new}$$

$$Emissions_{new} = 1573.2\,ton$$

Total Emissions of Older Vehicles, (English Tons):

Carbon Monoxide:

$LDV9295_{CO} = 714.3\,ton$ $LDV8291_{CO} = 647.1\,ton$ $LDVP82_{CO} = 500\,ton$

$LDT9295_{CO} = 525.3\,ton$ $LDT8291_{CO} = 419.4\,ton$ $LDTP82_{CO} = 126.5\,ton$

$$CO_{old} := LDV9295_{CO} + LDT9295_{CO} + LDV8291_{CO} + LDT8291_{CO} \cdots + LDVP82_{CO} + LDTP82_{CO}$$

Nitrous Oxides:

$LDV9295_{NOx} = 210.1\,ton$ $LDV8291_{NOx} = 154.1\,ton$ $LDVP82_{NOx} = 48.1\,ton$

$LDT9295_{NOx} = 63\,ton$ $LDT8291_{NOx} = 46.2\,ton$ $LDTP82_{NOx} = 14.2\,ton$

$$NOx_{old} := LDV9295_{NOx} + LDT9295_{NOx} + LDV8291_{NOx} + LDT8291_{NOx} \cdots + LDVP82_{NOx} + LDTP82_{NOx}$$

HydroCarbons and Volatile Organic Compounds:

$LDV9295_{HC} = 86.1\,ton$ $LDV8291_{VOC} = 123.3\,ton$ $LDVP82_{VOC} = 38.9\,ton$

$LDT9295_{HC} = 35.2\,ton$ $LDT8291_{VOC} = 30.8\,ton$ $LDTP82_{VOC} = 11.5\,ton$

$$HC_{old} := LDV9295_{HC} + LDT9295_{HC} + LDV8291_{VOC} + LDT8291_{VOC} \cdots + LDVP82_{VOC} + LDTP82_{VOC}$$

Totals for Older Vehicles:

$CO_{old} = 2932.7\,ton$ $NOx_{old} = 535.8\,ton$ $HC_{old} = 325.8\,ton$

$Emissions_{old} := CO_{old} + NOx_{old} + HC_{old}$

$Emissions_{old} = 3794.2\,ton$

Calculate emissions of a population of SLEV

$Number\_of\_SLEV := (0.10)\cdot\left(V\%_{old}\right)\cdot Worcester\_population\cdot Vehicles\_per\_person$

$Commuter\_miles_{SLEV} := (Travel\_distance)\cdot\left(\frac{2}{day}\right)\cdot(Work\_days)\cdot(Number\_of\_SLEV)$

$Commuter\_miles_{SLEV} = 0.04\,billion\_miles$ driven per year

$Avg\_commuter\_miles_{SLEV} := \frac{Commuter\_miles_{SLE}}{Number\_of\_SLEV}$ $Avg\_commuter\_miles_{SLEV} = 3.654\times10^{3}\,mi$ per vehicle driven per year

$Weekend\_miles_{SLEV} := \left(\frac{Travel\_distance}{2}\right)\cdot\left(\frac{2}{day}\right)\cdot(Week\_ends)\cdot(Number\_of\_SLEV)$

$Weekend\_miles_{SLEV} = 8.063\,million\_miles$ driven per year

$Avg\_weekend\_miles_{SLEV} := \frac{Weekend\_miles_{SLEV}}{Number\_of\_SLEV}$ $Avg\_weekend\_miles_{SLEV} = 728\,mi$ per vehicle driven per year

$Total\_Worcester\_miles_{SLEV} := Weekend\_miles_{SLEV} + Commuter\_miles_{SLEV}$

$Total\_Worcester\_miles_{SLEV} = 0.049\,billion\_miles$ driven per year

$SLEV_{CO} := Total\_Worcester\_miles_{SLEV}\cdot SLEV\_CO$ $SLEV_{CO} = 53.498\,ton$

$SLEV_{HC} := Total\_Worcester\_miles_{SLEV}\cdot SLEV\_HC$ $SLEV_{HC} = 0.535\,ton$

$SLEV_{NOx} := Total\_Worcester\_miles_{SLEV}\cdot SLEV\_NOx$ $SLEV_{NOx} = 1.07\,ton$

$Total\_Emissions := Emissions_{new} + Emissions_{old} + SLEV_{CO} + SLEV_{HC} + SLEV_{NOx}$

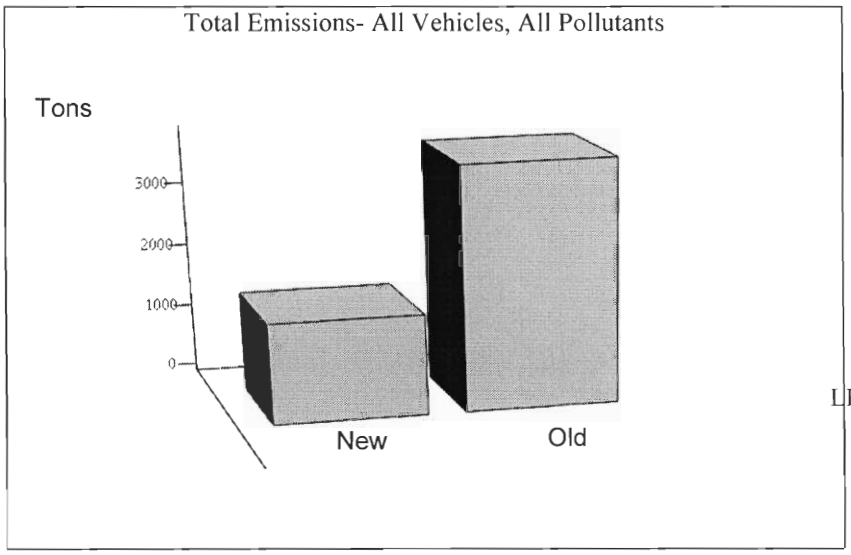
$Total\_Emissions = 5422.6\,ton$

$CO_{Tot} := SLEV_{CO} + CO_{old} + CO_{new}$ $CO_{Tot} = 4395.2\,ton$

$NOx_{Tot} := SLEV_{NOx} + NOx_{old} + NOx_{new}$ $NOx_{Tot} = 651.3\,ton$

$HC_{Tot} := SLEV_{HC} + HC_{old} + HC_{new}$ $HC_{Tot} = 376\,ton$

$$Graph1 := \left(\frac{Emissions_{new}}{2000} \quad \frac{Emissions_{old}}{2000} \right)$$



$LDTP82_{VOC} = 12.7\,to$

Replacing 25% of all Vehicles w/Hybrids

billion_miles := $10^9 \cdot mi$

million_miles := $10^6 \cdot mi$

Assumptions:

Vehicles traveling through Worcester Travel an average of 7 miles each

Travel_distance := $7 \cdot mi$

40% of the pollutants in the air come from vehicles

Work_days := $261 \cdot day$

Week_ends := $104 \cdot day$

City Data:

Worcester_population := 254900 people

Vehicles_per_person := 0.79

Percentages of Vehicle Types:

Newer Vehicles:

SUV := 0.275 SmC := 0.21 LMM := 0.51

Older Vehicles:

SUV_{old} := 0.20 SmC_{old} := 0.20 LMM_{old} := 0.60 LDT% := SUV_{old}

LDC% := $SmC_{old} + LMM_{old}$

Age distribution of Vehicles on the Roads:

1996 - 2002 V_{9602} := 0.45

1992 - 1995 V_{9295} := 0.30

1982 - 1991 V_{8291} := 0.22

Pre 1982 V_{P82} := 0.03

Transitional Low Emissions Vehicle Data:

TLEV_NMOG := $0.125 \cdot \frac{gm}{mi}$ TLEV_NOx := $0.4 \cdot \frac{gm}{mi}$

TLEV_CO := $3.4 \cdot \frac{gm}{mi}$ TLEV_HCHO := $0.015 \cdot \frac{gm}{mi}$

TLEV HC := TLEV NMOG + TLEV_HCHO

TLEV_HC = $0.14 \frac{gm}{mi}$

Low Emissions Vehicle Data:

LEV_NMOG := $0.075 \cdot \frac{gm}{mi}$ LEV_NOx := $0.2 \cdot \frac{gm}{mi}$

LEV_CO := $3.4 \cdot \frac{gm}{mi}$ LEV_HCHO := $0.015 \cdot \frac{gm}{mi}$

LEV_HC := LEV_NMOG + LEV_HCHO

LEV_HC = $0.09 \frac{gm}{mi}$

Ultra Low Emissions Vehicle Data:

$$ULEV\_NMOG := 0.04 \cdot \frac{gm}{mi} \qquad ULEV\_NOx := 0.2 \cdot \frac{gm}{mi}$$

$$ULEV\_CO := 1.7 \cdot \frac{gm}{mi} \qquad ULEV\_HCHO := 0.008 \cdot \frac{gm}{mi}$$

$$ULEV\_HC := ULEV\_NMOG + ULEV\_HCHO$$

$$ULEV\_HC = 0.048 \frac{gm}{mi}$$

Super Low Emissions Vehicle Data:

$$SLEV\_CO := 1.0 \cdot \frac{gm}{mi} \qquad SLEV\_HC := 0.01 \cdot \frac{gm}{mi} \qquad SLEV\_NOx := 0.02 \cdot \frac{gm}{mi}$$

Zero Emissions Vehicle Data:

$$ZEV\_CO := 0 \cdot \frac{gm}{mi} \qquad ZEV\_HC := 0 \cdot \frac{gm}{mi} \qquad ZEV\_NOx := 0 \cdot \frac{gm}{mi}$$

Tier 1 Emissions Data:

$$T1\_CO := 4.2 \cdot \frac{gm}{mi} \qquad T1\_HC := 0.31 \cdot \frac{gm}{mi} \qquad T1\_NOx := 0.6 \cdot \frac{gm}{mi}$$

Tabulated Vehicle Distribution for New Vehicles:

$$SUV\_ZEV\_percentage := \frac{0.21}{100} \qquad LMM\_ZEV\_percentage := 0$$

$$SUV\_SLEV\_percentage := \frac{0.86}{100} \qquad LMM\_SLEV\_percentage := \frac{0.36}{100}$$

$$SUV\_ULEV\_percentage := \frac{4.5}{100} \qquad LMM\_ULEV\_percentage := \frac{19.13}{100}$$

$$SUV\_LEV\_percentage := \frac{51.82}{100} \qquad LMM\_LEV\_percentage := \frac{70.40}{100}$$

$$SUV\_TLEV\_percentage := \frac{1.5}{100} \qquad LMM\_TLEV\_percentage := \frac{7.94}{100}$$

$$SUV\_T1\_percentage := \frac{41.11}{100} \qquad LMM\_T1\_percentage := \frac{2.17}{100}$$

$$SmC\_ZEV\_percentage := \frac{0.26}{100} \qquad SmC\_LEV\_percentage := \frac{65.17}{100}$$

$$SmC\_SLEV\_percentage := \frac{1.06}{100} \qquad SmC\_TLEV\_percentage := \frac{9.5}{100}$$

$$SmC\_ULEV\_percentage := \frac{15.04}{100} \qquad SmC\_T1\_percentage := \frac{8.97}{100}$$

Percentages of Each New Vehicle Type Observed on the Road:

SmC_on_road := .2395 LMM_on_road := .5418

SUV_on_road := .2187

Equations:

$$\text{Number\_of\_Vehicles} := \text{Worcester\_population} \cdot \text{Vehicles\_per\_person}$$

$$\text{Number\_of\_Vehicles} = 2.014 \times 10^{5}$$

$$\text{Commuter\_miles} := (\text{Travel\_distance}) \cdot \left(\frac{2}{\text{day}}\right) \cdot (\text{Work\_days}) \cdot (\text{Number\_of\_Vehicles})$$

$$\text{Commuter\_miles} = 0.736\,\text{billion\_miles driven per year}$$

$$\text{Avg\_commuter\_miles} := \frac{\text{Commuter\_miles}}{\text{Number\_of\_Vehicles}} \qquad \text{Avg\_commuter\_miles} = 3.654 \times 10^{3}\,\text{mi per vehicle driven per year}$$

$$\text{Weekend\_miles} := \left(\frac{\text{Travel\_distance}}{2}\right) \cdot \left(\frac{2}{\text{day}}\right) \cdot (\text{Week\_ends}) \cdot (\text{Number\_of\_Vehicles})$$

$$\text{Weekend\_miles} = 146.598\,\text{million\_milesriven per year}$$

$$\text{Avg\_weekend\_miles} := \frac{\text{Weekend\_miles}}{\text{Number\_of\_Vehicles}} \qquad \text{Avg\_weekend\_miles} = 728\,\text{mi per vehicle driven per year}$$

$$\text{Total\_Worcester\_miles} := \text{Weekend\_miles} + \text{Commuter\_miles} \qquad \text{Total\_Worcester\_miles} = 0.882\,\text{billion\_miles driven per year}$$

Emissions Due to New SUV's

$$\text{SUV}_{\text{NOx}} := V_{9602} \cdot \left[\begin{array}{l} (\text{Total\_Worcester\_miles}) \cdot (\text{SUV\_on\_road}) \cdot (\text{SUV\_ZEV\_percentage}) \cdot (\text{ZEV\_NOx}) \ldots \\ +(\text{Total\_Worcester\_miles}) \cdot (\text{SUV\_on\_road}) \cdot (\text{SUV\_SLEV\_percentage}) \cdot (\text{SLEV\_NOx}) \ldots \\ +(\text{Total\_Worcester\_miles}) \cdot (\text{SUV\_on\_road}) \cdot (\text{SUV\_T1\_percentage}) \cdot (\text{T1\_NOx}) \ldots \\ +(\text{Total\_Worcester\_miles}) \cdot (\text{SUV\_on\_road}) \cdot (\text{SUV\_TLEV\_percentage}) \cdot (\text{TLEV\_NOx}) \ldots \\ +(\text{Total\_Worcester\_miles}) \cdot (\text{SUV\_on\_road}) \cdot (\text{SUV\_LEV\_percentage}) \cdot (\text{LEV\_NOx}) \ldots \\ +(\text{Total\_Worcester\_miles}) \cdot (\text{SUV\_on\_road}) \cdot (\text{SUV\_ULEV\_percentage}) \cdot (\text{ULEV\_NOx}) \end{array}\right]$$

$$\text{SUV}_{\text{NOx}} = 3.174 \times 10^{7}\,\text{gm}$$

$$\text{SUV}_{\text{HC}} := V_{9602} \cdot \left[\begin{array}{l} (\text{Total\_Worcester\_miles}) \cdot (\text{SUV\_on\_road}) \cdot (\text{SUV\_ZEV\_percentage}) \cdot (\text{ZEV\_HC}) \ldots \\ +(\text{Total\_Worcester\_miles}) \cdot (\text{SUV\_on\_road}) \cdot (\text{SUV\_SLEV\_percentage}) \cdot (\text{SLEV\_HC}) \ldots \\ +(\text{Total\_Worcester\_miles}) \cdot (\text{SUV\_on\_road}) \cdot (\text{SUV\_T1\_percentage}) \cdot (\text{T1\_HC}) \ldots \\ +(\text{Total\_Worcester\_miles}) \cdot (\text{SUV\_on\_road}) \cdot (\text{SUV\_TLEV\_percentage}) \cdot (\text{TLEV\_HC}) \ldots \\ +(\text{Total\_Worcester\_miles}) \cdot (\text{SUV\_on\_road}) \cdot (\text{SUV\_LEV\_percentage}) \cdot (\text{LEV\_HC}) \ldots \\ +(\text{Total\_Worcester\_miles}) \cdot (\text{SUV\_on\_road}) \cdot (\text{SUV\_ULEV\_percentage}) \cdot (\text{ULEV\_HC}) \end{array}\right]$$

$$\text{SUV}_{\text{HC}} = 1.549 \times 10^{7}\,\text{gm}$$

$$SUV_{CO} := V_{9602} \cdot \left[\begin{array}{l} (Total\_Worcester\_miles) \cdot (SUV\_on\_road) \cdot (SUV\_ZEV\_percentage) \cdot (ZEV\_CO) \ldots \\ + (Total\_Worcester\_miles) \cdot (SUV\_on\_road) \cdot (SUV\_SLEV\_percentage) \cdot (SLEV\_CO) \ldots \\ + (Total\_Worcester\_miles) \cdot (SUV\_on\_road) \cdot (SUV\_T1\_percentage) \cdot (T1\_CO) \ldots \\ + (Total\_Worcester\_miles) \cdot (SUV\_on\_road) \cdot (SUV\_TLEV\_percentage) \cdot (TLEV\_CO) \ldots \\ + (Total\_Worcester\_miles) \cdot (SUV\_on\_road) \cdot (SUV\_LEV\_percentage) \cdot (LEV\_CO) \ldots \\ + (Total\_Worcester\_miles) \cdot (SUV\_on\_road) \cdot (SUV\_ULEV\_percentage) \cdot (ULEV\_CO) \end{array} \right]$$

$$SUV_{CO} = 3.148 \times 10^{8}\ gm$$

Emissions Due to New Small Cars

$$SmC_{NOx} := V_{9602} \cdot \left[\begin{array}{l} (Total\_Worcester\_miles) \cdot (SmC\_on\_road) \cdot (SmC\_ZEV\_percentage) \cdot (ZEV\_NOx) \ldots \\ + (Total\_Worcester\_miles) \cdot (SmC\_on\_road) \cdot (SmC\_SLEV\_percentage) \cdot (SLEV\_NOx) \ldots \\ + (Total\_Worcester\_miles) \cdot (SmC\_on\_road) \cdot (SmC\_T1\_percentage) \cdot (T1\_NOx) \ldots \\ + (Total\_Worcester\_miles) \cdot (SmC\_on\_road) \cdot (SmC\_TLEV\_percentage) \cdot (TLEV\_NOx) \ldots \\ + (Total\_Worcester\_miles) \cdot (SmC\_on\_road) \cdot (SmC\_LEV\_percentage) \cdot (LEV\_NOx) \ldots \\ + (Total\_Worcester\_miles) \cdot (SmC\_on\_road) \cdot (SmC\_ULEV\_percentage) \cdot (ULEV\_NOx) \end{array} \right]$$

$$SmC_{NOx} = 2.401 \times 10^{7}\ gm$$

$$SmC_{HC} := V_{9602} \cdot \left[\begin{array}{l} (Total\_Worcester\_miles) \cdot (SmC\_on\_road) \cdot (SmC\_ZEV\_percentage) \cdot (ZEV\_HC) \ldots \\ + (Total\_Worcester\_miles) \cdot (SmC\_on\_road) \cdot (SmC\_SLEV\_percentage) \cdot (SLEV\_HC) \ldots \\ + (Total\_Worcester\_miles) \cdot (SmC\_on\_road) \cdot (SmC\_T1\_percentage) \cdot (T1\_HC) \ldots \\ + (Total\_Worcester\_miles) \cdot (SmC\_on\_road) \cdot (SmC\_TLEV\_percentage) \cdot (TLEV\_HC) \ldots \\ + (Total\_Worcester\_miles) \cdot (SmC\_on\_road) \cdot (SmC\_LEV\_percentage) \cdot (LEV\_HC) \ldots \\ + (Total\_Worcester\_miles) \cdot (SmC\_on\_road) \cdot (SmC\_ULEV\_percentage) \cdot (ULEV\_HC) \end{array} \right]$$

$$SmC_{HC} = 1.018 \times 10^{7}\ gm$$

$$SmC_{CO} := V_{9602} \cdot \left[\begin{array}{l} (Total\_Worcester\_miles) \cdot (SmC\_on\_road) \cdot (SmC\_ZEV\_percentage) \cdot (ZEV\_CO) \ldots \\ + (Total\_Worcester\_miles) \cdot (SmC\_on\_road) \cdot (SmC\_SLEV\_percentage) \cdot (SLEV\_CO) \ldots \\ + (Total\_Worcester\_miles) \cdot (SmC\_on\_road) \cdot (SmC\_T1\_percentage) \cdot (T1\_CO) \ldots \\ + (Total\_Worcester\_miles) \cdot (SmC\_on\_road) \cdot (SmC\_TLEV\_percentage) \cdot (TLEV\_CO) \ldots \\ + (Total\_Worcester\_miles) \cdot (SmC\_on\_road) \cdot (SmC\_LEV\_percentage) \cdot (LEV\_CO) \ldots \\ + (Total\_Worcester\_miles) \cdot (SmC\_on\_road) \cdot (SmC\_ULEV\_percentage) \cdot (ULEV\_CO) \end{array} \right]$$

$$SmC_{CO} = 3.026 \times 10^{8}\ gm$$

Emissions Due to New Large-Medium cars and Minivans

$$LMM_{NOx} := V_{9602}\cdot\left[\begin{array}{l}(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_ZEV\_percentage)\cdot(ZEV\_NOx)\ ...\\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_SLEV\_percentage)\cdot(SLEV\_NOx)\ ...\\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_T1\_percentage)\cdot(T1\_NOx)\ ...\\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_TLEV\_percentage)\cdot(TLEV\_NOx)\ ...\\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_LEV\_percentage)\cdot(LEV\_NOx)\ ...\\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_ULEV\_percentage)\cdot(ULEV\_NOx)\end{array}\right]$$

$$LMM_{NOx} = 4.817\times 10^{7}\ gm$$

$$LMM_{HC} := V_{9602}\cdot\left[\begin{array}{l}(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_ZEV\_percentage)\cdot(ZEV\_HC)\ ...\\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_SLEV\_percentage)\cdot(SLEV\_HC)\ ...\\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_T1\_percentage)\cdot(T1\_HC)\ ...\\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_TLEV\_percentage)\cdot(TLEV\_HC)\ ...\\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_LEV\_percentage)\cdot(LEV\_HC)\ ...\\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_ULEV\_percentage)\cdot(ULEV\_HC)\end{array}\right]$$

$$LMM_{HC} = 1.945\times 10^{7}\ gm$$

$$LMM_{CO} := V_{9602}\cdot\left[\begin{array}{l}(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_ZEV\_percentage)\cdot(ZEV\_CO)\ ...\\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_SLEV\_percentage)\cdot(SLEV\_CO)\ ...\\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_T1\_percentage)\cdot(T1\_CO)\ ...\\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_TLEV\_percentage)\cdot(TLEV\_CO)\ ...\\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_LEV\_percentage)\cdot(LEV\_CO)\ ...\\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_ULEV\_percentage)\cdot(ULEV\_CO)\end{array}\right]$$

$$LMM_{CO} = 6.634\times 10^{8}\ gm$$

Emissions Due to Vehicles manufactured 1995 or before:

Note: Prior to 1996 vehicles were generally classified as either Light Duty Vehicles (LDV) or Light Dut Trucks (LDT)

Recalculated Old Vehicle Distributions

$LDV_{old} := SmC_{old} + LMM_{old}$ $LDV_{old} = 0.8$

$LDT_{old} := SUV_{old}$ $LDT_{old} = 0.2$

x100 percent distribution

1992 to 1995 Emissions Data:

By 1992, all vehicles had to conform to the following Federal standard:

$LDV\_9295_{CO} := 3.4 \cdot \frac{gm}{mi}$ $LDV\_9295_{HC} := 0.41 \cdot \frac{gm}{mi}$ $LDV\_9295_{NOx} := 1.0 \cdot \frac{gm}{mi}$

$LDT\_9295_{CO} := 10 \cdot \frac{gm}{mi}$ $LDT\_9295_{HC} := 0.67 \cdot \frac{gm}{mi}$ $LDT\_9295_{NOx} := 1.2 \cdot \frac{gm}{mi}$

1982 - 1991 Emissions Data:

In this time frame, HC were not regulated. Instead Volatile Organic Compounds (VOC) were the standard, and will be considered nearly equivalent to HC's

Vehicles older than 1991 have reached their full usefull life of 10 yrs / 100,000 mi

$LDV\_8291_{CO} := 4.2 \cdot \frac{gm}{mi}$ $LDV\_8291_{VOC} := 0.80 \cdot \frac{gm}{mi}$ $LDV\_8291_{NOx} := 1.0 \frac{gm}{mi}$

$LDT\_8291_{CO} := \frac{10 \cdot 8 + 18}{9} \cdot \frac{gm}{mi}$ $LDT\_8291_{VOC} := 0.80 \cdot \frac{gm}{mi}$ $LDT\_8291_{NOx} := 1.2 \cdot \frac{gm}{mi}$

Pre 1982 Data:

$LDV\_P82_{CO} := \frac{23 \cdot 2 + 39 \cdot 3 + 15 \cdot 5}{10} \cdot \frac{gm}{mi}$ $LDV\_P82_{NOx} := \frac{3 \cdot 3 + 3.1 \cdot 2 + 2 \cdot 4 + 1 \cdot 2}{11} \cdot \frac{gm}{mi}$

$LDV\_P82_{VOC} := \frac{3.4 \cdot 3 + 1.5 \cdot 5 + 0.41 \cdot 2}{10} \cdot \frac{gm}{mi}$

$LDT\_P82_{CO} := \frac{39 \cdot 3 + 20 \cdot 5 + 18 \cdot 4}{12} \cdot \frac{gm}{mi}$ $LDT\_P82_{VOC} := \frac{3.4 \cdot 3 + 2 \cdot 4 + 1.7 \cdot 6}{13} \cdot \frac{gm}{mi}$

$LDT\_P82_{NOx} := \frac{3 \cdot 3 + 3.1 \cdot 4 + 2.3 \cdot 6}{13} \cdot \frac{gm}{mi}$

Emissions Calculations:

1992 - 1995

$LDV9295_{CO} := V_{9295} \cdot (Total\_Worcester\_miles) \cdot LDV\_9295_{CO} \cdot LDC\%$ $LDV9295_{CO} = 7.2 \times 10^{8}\ gm$

$LDT9295_{CO} := V_{9295} \cdot (Total\_Worcester\_miles) \cdot LDT\_9295_{CO} \cdot LDT\%$ $LDT9295_{CO} = 5.294 \times 10^{8}\ gm$

$LDV9295_{NOx} := V_{9295} \cdot (Total\_Worcester\_miles) \cdot LDV\_9295_{NOx} \cdot LDC\%$ $LDV9295_{NOx} = 2.118 \times 10^{8}\ gm$

$LDT9295_{NOx} := V_{9295} \cdot (Total\_Worcester\_miles) \cdot LDT\_9295_{NOx} \cdot LDT\%$ $LDT9295_{NOx} = 6.353 \times 10^{7}\ gm$

$LDV9295_{HC} := V_{9295} \cdot (Total\_Worcester\_miles) \cdot LDV\_9295_{HC} \cdot LDC\%$ $LDV9295_{HC} = 8.683 \times 10^{7}\ gm$

$LDT9295_{HC} := V_{9295} \cdot (Total\_Worcester\_miles) \cdot LDT\_9295_{HC} \cdot LDT\%$ $LDT9295_{HC} = 3.547 \times 10^{7}\ gm$

1982-1991

$LDV8291_{CO} := V_{8291} \cdot (Total\_Worcester\_miles) \cdot LDV\_8291_{CO} \cdot LDC\%$ $LDV8291_{CO} = 6.523 \times 10^{8}\ gm$

$LDT8291_{CO} := V_{8291} \cdot (Total\_Worcester\_miles) \cdot LDT\_8291_{CO} \cdot LDT\%$ $LDT8291_{CO} = 4.228 \times 10^{8}\ gm$

$LDV8291_{NOx} := V_{8291} \cdot (Total\_Worcester\_miles) \cdot LDV\_8291_{NOx} \cdot LDC\%$ $LDV8291_{NOx} = 1.553 \times 10^{8}\ gm$

$LDT8291_{NOx} := V_{8291} \cdot (Total\_Worcester\_miles) \cdot LDT\_8291_{NOx} \cdot LDT\%$ $LDT8291_{NOx} = 4.659 \times 10^{7}\ gm$

$LDV8291_{VOC} := V_{8291} \cdot (Total\_Worcester\_miles) \cdot LDV\_8291_{VOC} \cdot LDC\%$ $LDV8291_{VOC} = 1.242 \times 10^{8}\ gm$

$LDT8291_{VOC} := V_{8291} \cdot (Total\_Worcester\_miles) \cdot LDT\_8291_{VOC} \cdot LDT\%$ $LDT8291_{VOC} = 3.106 \times 10^{7}\ gm$

Pre 1982

$LDVP82_{CO} := V_{P82} \cdot (Total\_Worcester\_miles) \cdot LDV\_P82_{CO} \cdot LDC\%$ $LDVP82_{CO} = 5.04 \times 10^{8}\ gm$

$LDTP82_{CO} := V_{P82} \cdot (Total\_Worcester\_miles) \cdot LDT\_P82_{CO} \cdot LDT\%$ $LDTP82_{CO} = 1.275 \times 10^{8}\ gm$

$LDVP82_{NOx} := V_{P82} \cdot (Total\_Worcester\_miles) \cdot LDV\_P82_{NOx} \cdot LDC\%$ $LDVP82_{NOx} = 4.852 \times 10^{7}\ gm$

$LDTP82_{NOx} := V_{P82} \cdot (Total\_Worcester\_miles) \cdot LDT\_P82_{NOx} \cdot LDT\%$ $LDTP82_{NOx} = 1.434 \times 10^{7}\ gm$

$LDVP82_{VOC} := V_{P82} \cdot (Total\_Worcester\_miles) \cdot LDV\_P82_{VOC} \cdot LDC\%$ $LDVP82_{VOC} = 3.922 \times 10^{7}\ gm$

$LDTP82_{VOC} := V_{P82} \cdot (Total\_Worcester\_miles) \cdot LDT\_P82_{VOC} \cdot LDT\%$ $LDTP82_{VOC} = 1.157 \times 10^{7}\ gm$

Total Emissions of New Vehicles, (English Tons):

Carbon Monoxide:

$$CO_{new} := LMM_{CO} + SmC_{CO} + SUV_{CO}$$

$$CO_{new} = 1411.8\,ton$$

$LMM_{CO} = 731.3\,ton$

$SmC_{CO} = 333.6\,ton$

$SUV_{CO} = 347\,ton$

Nitrous Oxides:

$$NOx_{new} := LMM_{NOx} + SmC_{NOx} + SUV_{NOx}$$

$$NOx_{new} = 114.6\,ton$$

$LMM_{NOx} = 53.1\,ton$

$SmC_{NOx} = 26.5\,ton$

$SUV_{NOx} = 35\,ton$

Hydocarbons:

$$HC_{new} := LMM_{HC} + SmC_{HC} + SUV_{HC}$$

$$HC_{new} = 49.7\,ton$$

$LMM_{HC} = 21.4\,ton$

$SmC_{HC} = 11.2\,ton$

$SUV_{HC} = 17.1\,ton$

Total Emissions:

$$Emissions_{new} := CO_{new} + NOx_{new} + HC_{new}$$

$$Emissions_{new} = 1576.1\,ton$$

Total Emissions of Older Vehicles, (English Tons):

Carbon Monoxide:

$LDV9295_{CO} = 793.7\,ton$ $LDV8291_{CO} = 719\,ton$ $LDVP82_{CO} = 555.6\,ton$

$LDT9295_{CO} = 583.6\,ton$ $LDT8291_{CO} = 466\,ton$ $LDTP82_{CO} = 140.6\,ton$

$$CO_{old} := LDV9295_{CO} + LDT9295_{CO} + LDV8291_{CO} + LDT8291_{CO} \ldots + LDVP82_{CO} + LDTP82_{CO}$$

Nitrous Oxides:

$LDV9295_{NOx} = 233.4\,ton$ $LDV8291_{NOx} = 171.2\,ton$ $LDVP82_{NOx} = 53.5\,ton$

$LDT9295_{NOx} = 70\,ton$ $LDT8291_{NOx} = 51.4\,ton$ $LDTP82_{NOx} = 15.8\,ton$

$$NOx_{old} := LDV9295_{NOx} + LDT9295_{NOx} + LDV8291_{NOx} + LDT8291_{NOx} \ldots + LDVP82_{NOx} + LDTP82_{NOx}$$

HydroCarbons and Volatile Organic Compounds:

$LDV9295_{HC} = 95.7\,ton$ $LDV8291_{VOC} = 137\,ton$ $LDVP82_{VOC} = 43.2\,ton$

$LDT9295_{HC} = 39.1\,ton$ $LDT8291_{VOC} = 34.2\,ton$ $LDTP82_{VOC} = 12.7\,ton$

$$HC_{old} := LDV9295_{HC} + LDT9295_{HC} + LDV8291_{VOC} + LDT8291_{VOC} \ldots + LDVP82_{VOC} + LDTP82_{VOC}$$

Totals for Older Vehicles:

$CO_{old} = 3258.5\,ton$ $NOx_{old} = 595.3\,ton$ $HC_{old} = 362\,ton$

$Emissions_{old} := CO_{old} + NOx_{old} + HC_{old}$

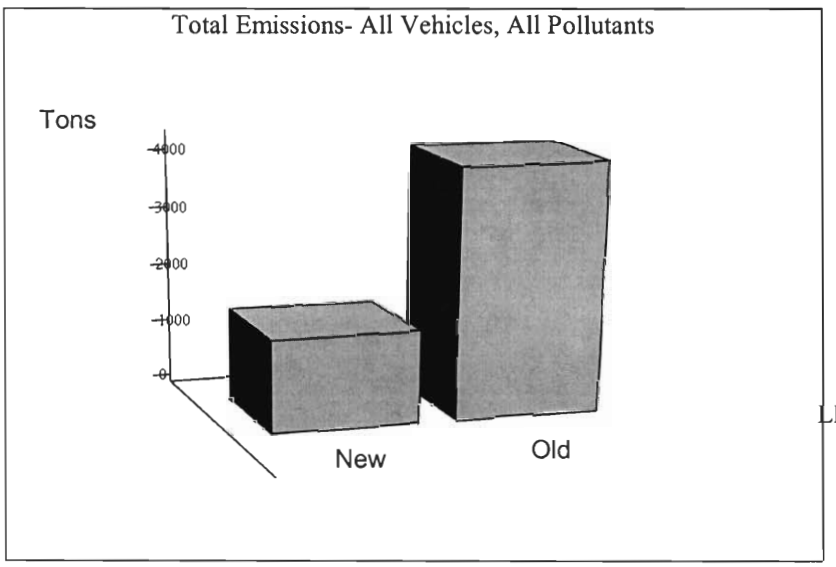
$Emissions_{old} = 4215.8\,ton$

$CO_{Tot} := CO_{old} + CO_{new}$ $CO_{Tot} = 4670.3\,ton$

$NOx_{Tot} := NOx_{old} + NOx_{new}$ $NOx_{Tot} = 709.9\,ton$

$HC_{Tot} := HC_{old} + HC_{new}$ $HC_{Tot} = 411.7\,ton$

$$Graph1 := \left(\frac{Emissions_{new}}{2000} \quad \frac{Emissions_{old}}{2000} \right)$$



$LDTP82_{VOC} = 12.7\,ton$

Replacing 25% of all new Vehicles w/Hybrids

billion_miles := $10^9 \cdot mi$

million_miles := $10^6 \cdot mi$

Assumptions:

Vehicles traveling through Worcester Travel an average of 7 miles each

Travel_distance := $7 \cdot mi$

Work_days := $261 \cdot day$

Week_ends := $104 \cdot day$

City Data:

Worcester_population := 254900 people

Vehicles_per_person := 0.79

Percentages of Vehicle Types:

Newer Vehicles:

SUV := 0.275 SmC := 0.21 LMM := 0.51

Older Vehicles:

SUV_{old} := 0.20 SmC_{old} := 0.20 LMM_{old} := 0.60 LDT% := SUV_{old}

LDC% := $SmC_{old} + LMM_{old}$

Age distribution of Vehicles on the Roads:

1996 - 2002 $V_{9602} := 0.45 \cdot (0.75)$

1992 - 1995 $V_{9295} := 0.30$

1982 - 1991 $V_{8291} := 0.22$

Pre 1982 $V_{P82} := 0.03$

$V\%_{new} := 0.45$

$V\%_{old} := 0.55$ 55% of all worcester vehicles are "old"

Transitional Low Emissions Vehicle Data:

TLEV_NMOG := $0.125 \cdot \frac{gm}{mi}$ TLEV_NOx := $0.4 \cdot \frac{gm}{mi}$

TLEV_CO := $3.4 \cdot \frac{gm}{mi}$ TLEV_HCHO := $0.015 \cdot \frac{gm}{mi}$

TLEV_HC := TLEV_NMOG + TLEV_HCHO

TLEV_HC = $0.14 \frac{gm}{mi}$

Low Emissions Vehicle Data:

LEV_NMOG := $0.075 \cdot \frac{gm}{mi}$ LEV_NOx := $0.2 \cdot \frac{gm}{mi}$

LEV_CO := $3.4 \cdot \frac{gm}{mi}$ LEV_HCHO := $0.015 \cdot \frac{gm}{mi}$

LEV_HC := LEV_NMOG + LEV_HCHO

LEV_HC = $0.09 \frac{gm}{mi}$

Ultra Low Emissions Vehicle Data:

$$ULEV\_NMOG := 0.04 \cdot \frac{gm}{mi} \qquad ULEV\_NOx := 0.2 \cdot \frac{gm}{mi}$$

$$ULEV\_CO := 1.7 \cdot \frac{gm}{mi} \qquad ULEV\_HCHO := 0.008 \cdot \frac{gm}{mi}$$

$$ULEV\_HC := ULEV\_NMOG + ULEV\_HCHO$$

$$ULEV\_HC = 0.048 \frac{gm}{mi}$$

Super Low Emissions Vehicle Data:

$$SLEV\_CO := 1.0 \cdot \frac{gm}{mi} \qquad SLEV\_HC := 0.01 \cdot \frac{gm}{mi} \qquad SLEV\_NOx := 0.02 \cdot \frac{gm}{mi}$$

Zero Emissions Vehicle Data:

$$ZEV\_CO := 0 \cdot \frac{gm}{mi} \qquad ZEV\_HC := 0 \cdot \frac{gm}{mi} \qquad ZEV\_NOx := 0 \cdot \frac{gm}{mi}$$

Tier 1 Emissions Data:

$$T1\_CO := 4.2 \cdot \frac{gm}{mi} \qquad T1\_HC := 0.31 \cdot \frac{gm}{mi} \qquad T1\_NOx := 0.6 \cdot \frac{gm}{mi}$$

Tabulated Vehicle Distribution for New Vehicles:

$$SUV\_ZEV\_percentage := \frac{0.21}{100} \qquad LMM\_ZEV\_percentage := 0$$

$$SUV\_SLEV\_percentage := \frac{0}{100} \qquad LMM\_SLEV\_percentage := \frac{0}{100}$$

$$SUV\_ULEV\_percentage := \frac{4.5}{100} \qquad LMM\_ULEV\_percentage := \frac{19.13}{100}$$

$$SUV\_LEV\_percentage := \frac{51.82}{100} \qquad LMM\_LEV\_percentage := \frac{70.40}{100}$$

$$SUV\_TLEV\_percentage := \frac{1.5}{100} \qquad LMM\_TLEV\_percentage := \frac{7.94}{100}$$

$$SUV\_T1\_percentage := \frac{41.11}{100} \qquad LMM\_T1\_percentage := \frac{2.17}{100}$$

$$SmC\_ZEV\_percentage := \frac{0.26}{100} \qquad SmC\_LEV\_percentage := \frac{65.17}{100}$$

$$SmC\_SLEV\_percentage := \frac{0}{100} \qquad SmC\_TLEV\_percentage := \frac{9.5}{100}$$

$$SmC\_ULEV\_percentage := \frac{15.04}{100} \qquad SmC\_T1\_percentage := \frac{8.97}{100}$$

Percentages of Each New Vehicle Type Observed on the Road:

SmC_on_road := .2395 LMM_on_road := .5418

SUV_on_road := .2187

Equations:

Number_of_Vehicles := 1.0·Worcester_population·Vehicles_per_person

Number_of_Vehicles = 201371

$$\text{Commuter\_miles} := (\text{Travel\_distance})\cdot\left(\frac{2}{\text{day}}\right)\cdot(\text{Work\_days})\cdot(\text{Number\_of\_Vehicles})$$

Commuter_miles = 0.736 billion_miles driven per year

$$\text{Avg\_commuter\_miles} := \frac{\text{Commuter\_miles}}{\text{Number\_of\_Vehicles}} \qquad \text{Avg\_commuter\_miles} = 3.654\times10^{3}\ \frac{\text{mi}}{\text{per vehicle driven per year}}$$

$$\text{Weekend\_miles} := \left(\frac{\text{Travel\_distance}}{2}\right)\cdot\left(\frac{2}{\text{day}}\right)\cdot(\text{Week\_ends})\cdot(\text{Number\_of\_Vehicles})$$

Weekend_miles = 146.598 million_milesriven per year

$$\text{Avg\_weekend\_miles} := \frac{\text{Weekend\_miles}}{\text{Number\_of\_Vehicles}} \qquad \text{Avg\_weekend\_miles} = 728\ \frac{\text{mi}}{\text{per vehicle driven per year}}$$

Total_Worcester_miles := Weekend_miles + Commuter_miles Total_Worcester_miles = 0.882 billion_miles driven per year

Emissions Due to New SUV's

$$\begin{aligned}\text{SUV}_{\text{NOx}} := V_{9602}\cdot\Big[&(\text{Total\_Worcester\_miles})\cdot(\text{SUV\_on\_road})\cdot(\text{SUV\_ZEV\_percentage})\cdot(\text{ZEV\_NOx})\ \ldots\\ &+(\text{Total\_Worcester\_miles})\cdot(\text{SUV\_on\_road})\cdot(\text{SUV\_SLEV\_percentage})\cdot(\text{SLEV\_NOx})\ \ldots\\ &+(\text{Total\_Worcester\_miles})\cdot(\text{SUV\_on\_road})\cdot(\text{SUV\_T1\_percentage})\cdot(\text{T1\_NOx})\ \ldots\\ &+(\text{Total\_Worcester\_miles})\cdot(\text{SUV\_on\_road})\cdot(\text{SUV\_TLEV\_percentage})\cdot(\text{TLEV\_NOx})\ \ldots\\ &+(\text{Total\_Worcester\_miles})\cdot(\text{SUV\_on\_road})\cdot(\text{SUV\_LEV\_percentage})\cdot(\text{LEV\_NOx})\ \ldots\\ &+(\text{Total\_Worcester\_miles})\cdot(\text{SUV\_on\_road})\cdot(\text{SUV\_ULEV\_percentage})\cdot(\text{ULEV\_NOx})\Big]\end{aligned}$$

$$\text{SUV}_{\text{NOx}} = 2.379\times10^{7}\ \text{gm}$$

$$\begin{aligned}\text{SUV}_{\text{HC}} := V_{9602}\cdot\Big[&(\text{Total\_Worcester\_miles})\cdot(\text{SUV\_on\_road})\cdot(\text{SUV\_ZEV\_percentage})\cdot(\text{ZEV\_HC})\ \ldots\\ &+(\text{Total\_Worcester\_miles})\cdot(\text{SUV\_on\_road})\cdot(\text{SUV\_SLEV\_percentage})\cdot(\text{SLEV\_HC})\ \ldots\\ &+(\text{Total\_Worcester\_miles})\cdot(\text{SUV\_on\_road})\cdot(\text{SUV\_T1\_percentage})\cdot(\text{T1\_HC})\ \ldots\\ &+(\text{Total\_Worcester\_miles})\cdot(\text{SUV\_on\_road})\cdot(\text{SUV\_TLEV\_percentage})\cdot(\text{TLEV\_HC})\ \ldots\\ &+(\text{Total\_Worcester\_miles})\cdot(\text{SUV\_on\_road})\cdot(\text{SUV\_LEV\_percentage})\cdot(\text{LEV\_HC})\ \ldots\\ &+(\text{Total\_Worcester\_miles})\cdot(\text{SUV\_on\_road})\cdot(\text{SUV\_ULEV\_percentage})\cdot(\text{ULEV\_HC})\Big]\end{aligned}$$

$$\text{SUV}_{\text{HC}} = 1.162\times10^{7}\ \text{gm}$$

$$SUV_{CO} := V_{9602}\cdot\begin{bmatrix} (Total\_Worcester\_miles)\cdot(SUV\_on\_road)\cdot(SUV\_ZEV\_percentage)\cdot(ZEV\_CO) \ldots \\ +(Total\_Worcester\_miles)\cdot(SUV\_on\_road)\cdot(SUV\_SLEV\_percentage)\cdot(SLEV\_CO) \ldots \\ +(Total\_Worcester\_miles)\cdot(SUV\_on\_road)\cdot(SUV\_T1\_percentage)\cdot(T1\_CO) \ldots \\ +(Total\_Worcester\_miles)\cdot(SUV\_on\_road)\cdot(SUV\_TLEV\_percentage)\cdot(TLEV\_CO) \ldots \\ +(Total\_Worcester\_miles)\cdot(SUV\_on\_road)\cdot(SUV\_LEV\_percentage)\cdot(LEV\_CO) \ldots \\ +(Total\_Worcester\_miles)\cdot(SUV\_on\_road)\cdot(SUV\_ULEV\_percentage)\cdot(ULEV\_CO) \end{bmatrix}$$

$$SUV_{CO} = 2.355 \times 10^{8}\ gm$$

Emissions Due to New Small Cars

$$SmC_{NOx} := V_{9602}\cdot\begin{bmatrix} (Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_ZEV\_percentage)\cdot(ZEV\_NOx) \ldots \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_SLEV\_percentage)\cdot(SLEV\_NOx) \ldots \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_T1\_percentage)\cdot(T1\_NOx) \ldots \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_TLEV\_percentage)\cdot(TLEV\_NOx) \ldots \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_LEV\_percentage)\cdot(LEV\_NOx) \ldots \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_ULEV\_percentage)\cdot(ULEV\_NOx) \end{bmatrix}$$

$$SmC_{NOx} = 1.799 \times 10^{7}\ gm$$

$$SmC_{HC} := V_{9602}\cdot\begin{bmatrix} (Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_ZEV\_percentage)\cdot(ZEV\_HC) \ldots \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_SLEV\_percentage)\cdot(SLEV\_HC) \ldots \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_T1\_percentage)\cdot(T1\_HC) \ldots \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_TLEV\_percentage)\cdot(TLEV\_HC) \ldots \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_LEV\_percentage)\cdot(LEV\_HC) \ldots \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_ULEV\_percentage)\cdot(ULEV\_HC) \end{bmatrix}$$

$$SmC_{HC} = 7.63 \times 10^{6}\ gm$$

$$SmC_{CO} := V_{9602}\cdot\begin{bmatrix} (Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_ZEV\_percentage)\cdot(ZEV\_CO) \ldots \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_SLEV\_percentage)\cdot(SLEV\_CO) \ldots \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_T1\_percentage)\cdot(T1\_CO) \ldots \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_TLEV\_percentage)\cdot(TLEV\_CO) \ldots \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_LEV\_percentage)\cdot(LEV\_CO) \ldots \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_ULEV\_percentage)\cdot(ULEV\_CO) \end{bmatrix}$$

$$SmC_{CO} = 2.262 \times 10^{8}\ gm$$

Emissions Due to New Large-Medium cars and Minivans

$$LMM_{NOx} := V_{9602}\cdot\left[\begin{array}{l}(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_ZEV\_percentage)\cdot(ZEV\_NOx)\ ...\\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_SLEV\_percentage)\cdot(SLEV\_NOx)\ ...\\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_T1\_percentage)\cdot(T1\_NOx)\ ...\\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_TLEV\_percentage)\cdot(TLEV\_NOx)\ ...\\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_LEV\_percentage)\cdot(LEV\_NOx)\ ...\\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_ULEV\_percentage)\cdot(ULEV\_NOx)\end{array}\right]$$

$$LMM_{NOx} = 3.612\times 10^{7}\ gm$$

$$LMM_{HC} := V_{9602}\cdot\left[\begin{array}{l}(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_ZEV\_percentage)\cdot(ZEV\_HC)\ ...\\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_SLEV\_percentage)\cdot(SLEV\_HC)\ ...\\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_T1\_percentage)\cdot(T1\_HC)\ ...\\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_TLEV\_percentage)\cdot(TLEV\_HC)\ ...\\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_LEV\_percentage)\cdot(LEV\_HC)\ ...\\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_ULEV\_percentage)\cdot(ULEV\_HC)\end{array}\right]$$

$$LMM_{HC} = 1.458\times 10^{7}\ gm$$

$$LMM_{CO} := V_{9602}\cdot\left[\begin{array}{l}(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_ZEV\_percentage)\cdot(ZEV\_CO)\ ...\\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_SLEV\_percentage)\cdot(SLEV\_CO)\ ...\\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_T1\_percentage)\cdot(T1\_CO)\ ...\\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_TLEV\_percentage)\cdot(TLEV\_CO)\ ...\\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_LEV\_percentage)\cdot(LEV\_CO)\ ...\\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_ULEV\_percentage)\cdot(ULEV\_CO)\end{array}\right]$$

$$LMM_{CO} = 4.97\times 10^{8}\ gm$$

Emissions Due to Vehicles manufactured 1995 or before:

Note: Prior to 1996 vehicles were generally classified as either Light Duty Vehicles (LDV) or Light Dut Trucks (LDT)

Recalculated Old Vehicle Distributions

$LDV_{old} := SmC_{old} + LMM_{old}$ $LDV_{old} = 0.8$

$LDT_{old} := SUV_{old}$ $LDT_{old} = 0.2$

x100 percent distribution

1992 to 1995 Emissions Data:

By 1992, all vehicles had to conform to the following Federal standard:

$LDV\_9295_{CO} := 3.4 \cdot \frac{gm}{mi}$ $LDV\_9295_{HC} := 0.41 \cdot \frac{gm}{mi}$ $LDV\_9295_{NOx} := 1.0 \cdot \frac{gm}{mi}$

$LDT\_9295_{CO} := 10 \cdot \frac{gm}{mi}$ $LDT\_9295_{HC} := 0.67 \cdot \frac{gm}{mi}$ $LDT\_9295_{NOx} := 1.2 \cdot \frac{gm}{mi}$

1982 - 1991 Emissions Data:

In this time frame, HC were not regulated. Instead Volatile Organic Compounds (VOC) were the standard, and will be considered nearly equivalent to HC's

Vehicles older than 1991 have reached their full usefull life of 10 yrs / 100,000 mi

$LDV\_8291_{CO} := 4.2 \cdot \frac{gm}{mi}$ $LDV\_8291_{VOC} := 0.80 \cdot \frac{gm}{mi}$ $LDV\_8291_{NOx} := 1.0 \frac{gm}{mi}$

$LDT\_8291_{CO} := \frac{10 \cdot 8 + 18}{9} \cdot \frac{gm}{mi}$ $LDT\_8291_{VOC} := 0.80 \cdot \frac{gm}{mi}$ $LDT\_8291_{NOx} := 1.2 \cdot \frac{gm}{mi}$

Pre 1982 Data:

$LDV\_P82_{CO} := \frac{23 \cdot 2 + 39 \cdot 3 + 15 \cdot 5}{10} \cdot \frac{gm}{mi}$ $LDV\_P82_{NOx} := \frac{3 \cdot 3 + 3.1 \cdot 2 + 2 \cdot 4 + 1 \cdot 2}{11} \cdot \frac{gm}{mi}$

$LDV\_P82_{VOC} := \frac{3.4 \cdot 3 + 1.5 \cdot 5 + 0.41 \cdot 2}{10} \cdot \frac{gm}{mi}$

$LDT\_P82_{CO} := \frac{39 \cdot 3 + 20 \cdot 5 + 18 \cdot 4}{12} \cdot \frac{gm}{mi}$ $LDT\_P82_{VOC} := \frac{3.4 \cdot 3 + 2 \cdot 4 + 1.7 \cdot 6}{13} \cdot \frac{gm}{mi}$

$LDT\_P82_{NOx} := \frac{3 \cdot 3 + 3.1 \cdot 4 + 2.3 \cdot 6}{13} \cdot \frac{gm}{mi}$

Emissions Calculations:

1992 - 1995

$LDV9295_{CO} := V_{9295} \cdot (Total\_Worcester\_miles) \cdot LDV\_9295_{CO} \cdot LDC\%$ $LDV9295_{CO} = 7.2 \times 10^{8}\ gm$

$LDT9295_{CO} := V_{9295} \cdot (Total\_Worcester\_miles) \cdot LDT\_9295_{CO} \cdot LDT\%$ $LDT9295_{CO} = 5.294 \times 10^{8}\ gm$

$LDV9295_{NOx} := V_{9295} \cdot (Total\_Worcester\_miles) \cdot LDV\_9295_{NOx} \cdot LDC\%$ $LDV9295_{NOx} = 2.118 \times 10^{8}\ gm$

$LDT9295_{NOx} := V_{9295} \cdot (Total\_Worcester\_miles) \cdot LDT\_9295_{NOx} \cdot LDT\%$ $LDT9295_{NOx} = 6.353 \times 10^{7}\ gm$

$LDV9295_{HC} := V_{9295} \cdot (Total\_Worcester\_miles) \cdot LDV\_9295_{HC} \cdot LDC\%$ $LDV9295_{HC} = 8.683 \times 10^{7}\ gm$

$LDT9295_{HC} := V_{9295} \cdot (Total\_Worcester\_miles) \cdot LDT\_9295_{HC} \cdot LDT\%$ $LDT9295_{HC} = 3.547 \times 10^{7}\ gm$

1982-1991

$LDV8291_{CO} := V_{8291} \cdot (Total\_Worcester\_miles) \cdot LDV\_8291_{CO} \cdot LDC\%$ $LDV8291_{CO} = 6.523 \times 10^{8}\ gm$

$LDT8291_{CO} := V_{8291} \cdot (Total\_Worcester\_miles) \cdot LDT\_8291_{CO} \cdot LDT\%$ $LDT8291_{CO} = 4.228 \times 10^{8}\ gm$

$LDV8291_{NOx} := V_{8291} \cdot (Total\_Worcester\_miles) \cdot LDV\_8291_{NOx} \cdot LDC\%$ $LDV8291_{NOx} = 1.553 \times 10^{8}\ gm$

$LDT8291_{NOx} := V_{8291} \cdot (Total\_Worcester\_miles) \cdot LDT\_8291_{NOx} \cdot LDT\%$ $LDT8291_{NOx} = 4.659 \times 10^{7}\ gm$

$LDV8291_{VOC} := V_{8291} \cdot (Total\_Worcester\_miles) \cdot LDV\_8291_{VOC} \cdot LDC\%$ $LDV8291_{VOC} = 1.242 \times 10^{8}\ gm$

$LDT8291_{VOC} := V_{8291} \cdot (Total\_Worcester\_miles) \cdot LDT\_8291_{VOC} \cdot LDT\%$ $LDT8291_{VOC} = 3.106 \times 10^{7}\ gm$

Pre 1982

$LDVP82_{CO} := V_{P82} \cdot (Total\_Worcester\_miles) \cdot LDV\_P82_{CO} \cdot LDC\%$ $LDVP82_{CO} = 5.04 \times 10^{8}\ gm$

$LDTP82_{CO} := V_{P82} \cdot (Total\_Worcester\_miles) \cdot LDT\_P82_{CO} \cdot LDT\%$ $LDTP82_{CO} = 1.275 \times 10^{8}\ gm$

$LDVP82_{NOx} := V_{P82} \cdot (Total\_Worcester\_miles) \cdot LDV\_P82_{NOx} \cdot LDC\%$ $LDVP82_{NOx} = 4.852 \times 10^{7}\ gm$

$LDTP82_{NOx} := V_{P82} \cdot (Total\_Worcester\_miles) \cdot LDT\_P82_{NOx} \cdot LDT\%$ $LDTP82_{NOx} = 1.434 \times 10^{7}\ gm$

$LDVP82_{VOC} := V_{P82} \cdot (Total\_Worcester\_miles) \cdot LDV\_P82_{VOC} \cdot LDC\%$ $LDVP82_{VOC} = 3.922 \times 10^{7}\ gm$

$LDTP82_{VOC} := V_{P82} \cdot (Total\_Worcester\_miles) \cdot LDT\_P82_{VOC} \cdot LDT\%$ $LDTP82_{VOC} = 1.157 \times 10^{7}\ gm$

Total Emissions of New Vehicles, (English Tons):

Carbon Monoxide:

$CO_{new} := LMM_{CO} + SmC_{CO} + SUV_{CO}$

$CO_{new} = 1056.7\,ton$

$LMM_{CO} = 547.8\,ton$

$SmC_{CO} = 249.3\,ton$

$SUV_{CO} = 259.6\,ton$

Nitrous Oxides:

$NOx_{new} := LMM_{NOx} + SmC_{NOx} + SUV_{NOx}$

$NOx_{new} = 85.9\,ton$

$LMM_{NOx} = 39.8\,ton$

$SmC_{NOx} = 19.8\,ton$

$SUV_{NOx} = 26.2\,ton$

Hydocarbons:

$HC_{new} := LMM_{HC} + SmC_{HC} + SUV_{HC}$

$HC_{new} = 37.3\,ton$

$LMM_{HC} = 16.1\,ton$

$SmC_{HC} = 8.4\,ton$

$SUV_{HC} = 12.8\,ton$

Total Emissions:

$Emissions_{new} := CO_{new} + NOx_{new} + HC_{new}$

$Emissions_{new} = 1179.9\,ton$

Total Emissions of Older Vehicles, (English Tons):

Carbon Monoxide:

$LDV9295_{CO} = 793.7\,ton$ $LDV8291_{CO} = 719\,ton$ $LDVP82_{CO} = 555.6\,ton$

$LDT9295_{CO} = 583.6\,ton$ $LDT8291_{CO} = 466\,ton$ $LDTP82_{CO} = 140.6\,ton$

$CO_{old} := LDV9295_{CO} + LDT9295_{CO} + LDV8291_{CO} + LDT8291_{CO} \ldots$
$+ LDVP82_{CO} + LDTP82_{CO}$

Nitrous Oxides:

$LDV9295_{NOx} = 233.4\,ton$ $LDV8291_{NOx} = 171.2\,ton$ $LDVP82_{NOx} = 53.5\,ton$

$LDT9295_{NOx} = 70\,ton$ $LDT8291_{NOx} = 51.4\,ton$ $LDTP82_{NOx} = 15.8\,ton$

$NOx_{old} := LDV9295_{NOx} + LDT9295_{NOx} + LDV8291_{NOx} + LDT8291_{NOx} \ldots$
$+ LDVP82_{NOx} + LDTP82_{NOx}$

HydroCarbons and Volatile Organic Compounds:

$LDV9295_{HC} = 95.7\,ton$ $LDV8291_{VOC} = 137\,ton$ $LDVP82_{VOC} = 43.2\,ton$

$LDT9295_{HC} = 39.1\,ton$ $LDT8291_{VOC} = 34.2\,ton$ $LDTP82_{VOC} = 12.7\,ton$

$HC_{old} := LDV9295_{HC} + LDT9295_{HC} + LDV8291_{VOC} + LDT8291_{VOC} \ldots$
$+ LDVP82_{VOC} + LDTP82_{VOC}$

Totals for Older Vehicles:

$CO_{old} = 3258.5\,ton$ $NOx_{old} = 595.3\,ton$ $HC_{old} = 362\,ton$

$Emissions_{old} := CO_{old} + NOx_{old} + HC_{old}$

$Emissions_{old} = 4215.8\,ton$

Calculate emissions of a population of 25% SLEV

$Number\_of\_SLEV := (0.25)\cdot\left(V\%_{new}\right)\cdot Worcester\_population\cdot Vehicles\_per\_person$

$Commuter\_miles_{SLEV} := (Travel\_distance)\cdot\left(\frac{2}{day}\right)\cdot(Work\_days)\cdot(Number\_of\_SLEV)$

$Commuter\_miles_{SLEV} = 0.083\,billion\_miles$ driven per year

$Avg\_commuter\_miles_{SLEV} := \frac{Commuter\_miles_{SLE}}{Number\_of\_SLEV}$ $Avg\_commuter\_miles_{SLEV} = 3.654 \times 10^{3}\,mi$ per vehicle driven per year

$Weekend\_miles_{SLEV} := \left(\frac{Travel\_distance}{2}\right)\cdot\left(\frac{2}{day}\right)\cdot(Week\_ends)\cdot(Number\_of\_SLEV)$

$Weekend\_miles_{SLEV} = 16.492\,million\_miles$ driven per year

$Avg\_weekend\_miles_{SLEV} := \frac{Weekend\_miles_{SLEV}}{Number\_of\_SLEV}$ $Avg\_weekend\_miles_{SLEV} = 728\,mi$ per vehicle driven per year

$Total\_Worcester\_miles_{SLEV} := Weekend\_miles_{SLEV} + Commuter\_miles_{SLEV}$

$Total\_Worcester\_miles_{SLEV} = 0.099\,billion\_miles$ driven per year

$SLEV_{CO} := Total\_Worcester\_miles_{SLEV}\cdot SLEV\_CO$ $SLEV_{CO} = 109.427\,ton$

$SLEV_{HC} := Total\_Worcester\_miles_{SLEV}\cdot SLEV\_HC$ $SLEV_{HC} = 1.094\,ton$

$SLEV_{NOx} := Total\_Worcester\_miles_{SLEV}\cdot SLEV\_NOx$ $SLEV_{NOx} = 2.189\,ton$

$Total\_Emissions := Emissions_{new} + Emissions_{old} + SLEV_{CO} + SLEV_{HC} + SLEV_{NOx}$

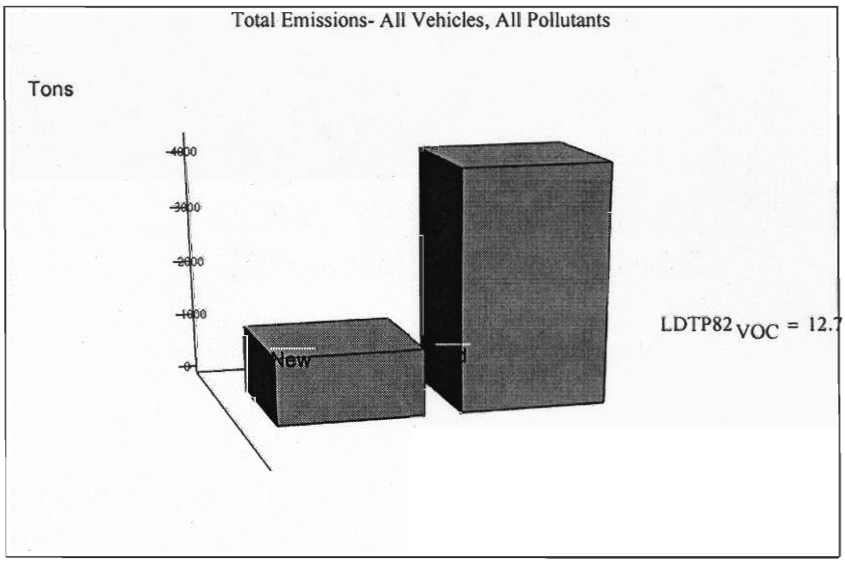
$Total\_Emissions = 5508.4\,ton$

$CO_{Tot} := SLEV_{CO} + CO_{old} + CO_{new}$ $CO_{Tot} = 4424.7\,ton$

$NOx_{Tot} := SLEV_{NOx} + NOx_{old} + NOx_{new}$ $NOx_{Tot} = 683.4\,ton$

$HC_{Tot} := SLEV_{HC} + HC_{old} + HC_{new}$ $HC_{Tot} = 400.4\,ton$

$$Graph1 := \left(\frac{Emissions_{new}}{2000} \quad \frac{Emissions_{old}}{2000} \right)$$



$LDTP82_{VOC} = 12.7\,tor$

Replacing 25% of all old Vehicles w/Hybrids

billion_miles := $10^9 \cdot mi$

million_miles := $10^6 \cdot mi$

Assumptions:

Vehicles traveling through Worcester Travel an average of 7 miles each

Travel_distance := $7 \cdot mi$

Work_days := $261 \cdot day$

Week_ends := $104 \cdot day$

City Data:

Worcester_population := 254900 people

Vehicles_per_person := 0.79

Percentages of Vehicle Types:

Newer Vehicles:

SUV := 0.275 SmC := 0.21 LMM := 0.51

Older Vehicles:

SUV_{old} := 0.20 SmC_{old} := 0.20 LMM_{old} := 0.60 LDT% := SUV_{old}

LDC% := $SmC_{old} + LMM_{old}$

Age distribution of Vehicles on the Roads:

1996 - 2002 $V_{9602} := 0.45$

1992 - 1995 $V_{9295} := 0.30 \cdot (0.75)$

1982 - 1991 $V_{8291} := 0.22(0.75)$

Pre 1982 $V_{P82} := 0.03 \cdot (0.75)$

$V\%_{old} := 0.55$ 55% of all worcester vehicles are "old"

Transitional Low Emissions Vehicle Data:

TLEV_NMOG := $0.125 \cdot \frac{gm}{mi}$ TLEV_NOx := $0.4 \cdot \frac{gm}{mi}$

TLEV_CO := $3.4 \cdot \frac{gm}{mi}$ TLEV_HCHO := $0.015 \cdot \frac{gm}{mi}$

TLEV HC := TLEV NMOG + TLEV_HCHO

TLEV_HC = $0.14 \frac{gm}{mi}$

Low Emissions Vehicle Data:

LEV_NMOG := $0.075 \cdot \frac{gm}{mi}$ LEV_NOx := $0.2 \cdot \frac{gm}{mi}$

LEV_CO := $3.4 \cdot \frac{gm}{mi}$ LEV_HCHO := $0.015 \cdot \frac{gm}{mi}$

LEV_HC := LEV_NMOG + LEV_HCHO

LEV_HC = $0.09 \frac{gm}{mi}$

Ultra Low Emissions Vehicle Data:

$$ULEV\_NMOG := 0.04 \cdot \frac{gm}{mi} \qquad ULEV\_NOx := 0.2 \cdot \frac{gm}{mi}$$

$$ULEV\_CO := 1.7 \cdot \frac{gm}{mi} \qquad ULEV\_HCHO := 0.008 \cdot \frac{gm}{mi}$$

$$ULEV\_HC := ULEV\_NMOG + ULEV\_HCHO$$

$$ULEV\_HC = 0.048 \frac{gm}{mi}$$

Super Low Emissions Vehicle Data:

$$SLEV\_CO := 1.0 \cdot \frac{gm}{mi} \qquad SLEV\_HC := 0.01 \cdot \frac{gm}{mi} \qquad SLEV\_NOx := 0.02 \cdot \frac{gm}{mi}$$

Zero Emissions Vehicle Data:

$$ZEV\_CO := 0 \cdot \frac{gm}{mi} \qquad ZEV\_HC := 0 \cdot \frac{gm}{mi} \qquad ZEV\_NOx := 0 \cdot \frac{gm}{mi}$$

Tier 1 Emissions Data:

$$T1\_CO := 4.2 \cdot \frac{gm}{mi} \qquad T1\_HC := 0.31 \cdot \frac{gm}{mi} \qquad T1\_NOx := 0.6 \cdot \frac{gm}{mi}$$

Tabulated Vehicle Distribution for New Vehicles:

$$SUV\_ZEV\_percentage := \frac{0.21}{100} \qquad LMM\_ZEV\_percentage := 0$$

$$SUV\_SLEV\_percentage := \frac{0}{100} \qquad LMM\_SLEV\_percentage := \frac{0}{100}$$

$$SUV\_ULEV\_percentage := \frac{4.5}{100} \qquad LMM\_ULEV\_percentage := \frac{19.13}{100}$$

$$SUV\_LEV\_percentage := \frac{51.82}{100} \qquad LMM\_LEV\_percentage := \frac{70.40}{100}$$

$$SUV\_TLEV\_percentage := \frac{1.5}{100} \qquad LMM\_TLEV\_percentage := \frac{7.94}{100}$$

$$SUV\_T1\_percentage := \frac{41.11}{100} \qquad LMM\_T1\_percentage := \frac{2.17}{100}$$

$$SmC\_ZEV\_percentage := \frac{0.26}{100} \qquad SmC\_LEV\_percentage := \frac{65.17}{100}$$

$$SmC\_SLEV\_percentage := \frac{0}{100} \qquad SmC\_TLEV\_percentage := \frac{9.5}{100}$$

$$SmC\_ULEV\_percentage := \frac{15.04}{100} \qquad SmC\_T1\_percentage := \frac{8.97}{100}$$

Percentages of Each New Vehicle Type Observed on the Road:

SmC_on_road := .2395 LMM_on_road := .5418

SUV_on_road := .2187

Equations:

Number_of_Vehicles := 1.0·Worcester_population·Vehicles_per_person

Number_of_Vehicles = 201371

$$\text{Commuter\_miles} := (\text{Travel\_distance})\cdot\left(\frac{2}{\text{day}}\right)\cdot(\text{Work\_days})\cdot(\text{Number\_of\_Vehicles})$$

Commuter_miles = 0.736 billion_miles driven per year

$$\text{Avg\_commuter\_miles} := \frac{\text{Commuter\_miles}}{\text{Number\_of\_Vehicles}} \qquad \text{Avg\_commuter\_miles} = 3.654\times 10^{3}\ \text{mi per vehicle driven per year}$$

$$\text{Weekend\_miles} := \left(\frac{\text{Travel\_distance}}{2}\right)\cdot\left(\frac{2}{\text{day}}\right)\cdot(\text{Week\_ends})\cdot(\text{Number\_of\_Vehicles})$$

Weekend_miles = 146.598 million_milesriven per year

$$\text{Avg\_weekend\_miles} := \frac{\text{Weekend\_miles}}{\text{Number\_of\_Vehicles}} \qquad \text{Avg\_weekend\_miles} = 728\ \text{mi per vehicle driven per year}$$

Total_Worcester_miles := Weekend_miles + Commuter_miles Total_Worcester_miles = 0.882 billion_miles driven per year

Emissions Due to New SUV's

$$\text{SUV}_{\text{NOx}} := V_{9602}\cdot\left[\begin{array}{l}(\text{Total\_Worcester\_miles})\cdot(\text{SUV\_on\_road})\cdot(\text{SUV\_ZEV\_percentage})\cdot(\text{ZEV\_NOx})\ \ldots\\ +(\text{Total\_Worcester\_miles})\cdot(\text{SUV\_on\_road})\cdot(\text{SUV\_SLEV\_percentage})\cdot(\text{SLEV\_NOx})\ \ldots\\ +(\text{Total\_Worcester\_miles})\cdot(\text{SUV\_on\_road})\cdot(\text{SUV\_T1\_percentage})\cdot(\text{T1\_NOx})\ \ldots\\ +(\text{Total\_Worcester\_miles})\cdot(\text{SUV\_on\_road})\cdot(\text{SUV\_TLEV\_percentage})\cdot(\text{TLEV\_NOx})\ \ldots\\ +(\text{Total\_Worcester\_miles})\cdot(\text{SUV\_on\_road})\cdot(\text{SUV\_LEV\_percentage})\cdot(\text{LEV\_NOx})\ \ldots\\ +(\text{Total\_Worcester\_miles})\cdot(\text{SUV\_on\_road})\cdot(\text{SUV\_ULEV\_percentage})\cdot(\text{ULEV\_NOx})\end{array}\right]$$

$$\text{SUV}_{\text{NOx}} = 3.172\times 10^{7}\ \text{gm}$$

$$\text{SUV}_{\text{HC}} := V_{9602}\cdot\left[\begin{array}{l}(\text{Total\_Worcester\_miles})\cdot(\text{SUV\_on\_road})\cdot(\text{SUV\_ZEV\_percentage})\cdot(\text{ZEV\_HC})\ \ldots\\ +(\text{Total\_Worcester\_miles})\cdot(\text{SUV\_on\_road})\cdot(\text{SUV\_SLEV\_percentage})\cdot(\text{SLEV\_HC})\ \ldots\\ +(\text{Total\_Worcester\_miles})\cdot(\text{SUV\_on\_road})\cdot(\text{SUV\_T1\_percentage})\cdot(\text{T1\_HC})\ \ldots\\ +(\text{Total\_Worcester\_miles})\cdot(\text{SUV\_on\_road})\cdot(\text{SUV\_TLEV\_percentage})\cdot(\text{TLEV\_HC})\ \ldots\\ +(\text{Total\_Worcester\_miles})\cdot(\text{SUV\_on\_road})\cdot(\text{SUV\_LEV\_percentage})\cdot(\text{LEV\_HC})\ \ldots\\ +(\text{Total\_Worcester\_miles})\cdot(\text{SUV\_on\_road})\cdot(\text{SUV\_ULEV\_percentage})\cdot(\text{ULEV\_HC})\end{array}\right]$$

$$\text{SUV}_{\text{HC}} = 1.549\times 10^{7}\ \text{gm}$$

$$SUV_{CO} := V_{9602}\cdot\begin{bmatrix} (Total\_Worcester\_miles)\cdot(SUV\_on\_road)\cdot(SUV\_ZEV\_percentage)\cdot(ZEV\_CO) \ldots \\ +(Total\_Worcester\_miles)\cdot(SUV\_on\_road)\cdot(SUV\_SLEV\_percentage)\cdot(SLEV\_CO) \ldots \\ +(Total\_Worcester\_miles)\cdot(SUV\_on\_road)\cdot(SUV\_T1\_percentage)\cdot(T1\_CO) \ldots \\ +(Total\_Worcester\_miles)\cdot(SUV\_on\_road)\cdot(SUV\_TLEV\_percentage)\cdot(TLEV\_CO) \ldots \\ +(Total\_Worcester\_miles)\cdot(SUV\_on\_road)\cdot(SUV\_LEV\_percentage)\cdot(LEV\_CO) \ldots \\ +(Total\_Worcester\_miles)\cdot(SUV\_on\_road)\cdot(SUV\_ULEV\_percentage)\cdot(ULEV\_CO) \end{bmatrix}$$

$$SUV_{CO} = 3.14 \times 10^{8}\ gm$$

Emissions Due to New Small Cars

$$SmC_{NOx} := V_{9602}\cdot\begin{bmatrix} (Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_ZEV\_percentage)\cdot(ZEV\_NOx) \ldots \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_SLEV\_percentage)\cdot(SLEV\_NOx) \ldots \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_T1\_percentage)\cdot(T1\_NOx) \ldots \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_TLEV\_percentage)\cdot(TLEV\_NOx) \ldots \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_LEV\_percentage)\cdot(LEV\_NOx) \ldots \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_ULEV\_percentage)\cdot(ULEV\_NOx) \end{bmatrix}$$

$$SmC_{NOx} = 2.399 \times 10^{7}\ gm$$

$$SmC_{HC} := V_{9602}\cdot\begin{bmatrix} (Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_ZEV\_percentage)\cdot(ZEV\_HC) \ldots \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_SLEV\_percentage)\cdot(SLEV\_HC) \ldots \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_T1\_percentage)\cdot(T1\_HC) \ldots \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_TLEV\_percentage)\cdot(TLEV\_HC) \ldots \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_LEV\_percentage)\cdot(LEV\_HC) \ldots \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_ULEV\_percentage)\cdot(ULEV\_HC) \end{bmatrix}$$

$$SmC_{HC} = 1.017 \times 10^{7}\ gm$$

$$SmC_{CO} := V_{9602}\cdot\begin{bmatrix} (Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_ZEV\_percentage)\cdot(ZEV\_CO) \ldots \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_SLEV\_percentage)\cdot(SLEV\_CO) \ldots \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_T1\_percentage)\cdot(T1\_CO) \ldots \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_TLEV\_percentage)\cdot(TLEV\_CO) \ldots \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_LEV\_percentage)\cdot(LEV\_CO) \ldots \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_ULEV\_percentage)\cdot(ULEV\_CO) \end{bmatrix}$$

$$SmC_{CO} = 3.016 \times 10^{8}\ gm$$

Emissions Due to New Large-Medium cars and Minivans

$$LMM_{NOx} := V_{9602}\cdot\left[\begin{array}{l}(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_ZEV\_percentage)\cdot(ZEV\_NOx)\ ...\\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_SLEV\_percentage)\cdot(SLEV\_NOx)\ ...\\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_T1\_percentage)\cdot(T1\_NOx)\ ...\\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_TLEV\_percentage)\cdot(TLEV\_NOx)\ ...\\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_LEV\_percentage)\cdot(LEV\_NOx)\ ...\\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_ULEV\_percentage)\cdot(ULEV\_NOx)\end{array}\right]$$

$$LMM_{NOx} = 4.816\times 10^{7}\ gm$$

$$LMM_{HC} := V_{9602}\cdot\left[\begin{array}{l}(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_ZEV\_percentage)\cdot(ZEV\_HC)\ ...\\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_SLEV\_percentage)\cdot(SLEV\_HC)\ ...\\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_T1\_percentage)\cdot(T1\_HC)\ ...\\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_TLEV\_percentage)\cdot(TLEV\_HC)\ ...\\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_LEV\_percentage)\cdot(LEV\_HC)\ ...\\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_ULEV\_percentage)\cdot(ULEV\_HC)\end{array}\right]$$

$$LMM_{HC} = 1.945\times 10^{7}\ gm$$

$$LMM_{CO} := V_{9602}\cdot\left[\begin{array}{l}(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_ZEV\_percentage)\cdot(ZEV\_CO)\ ...\\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_SLEV\_percentage)\cdot(SLEV\_CO)\ ...\\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_T1\_percentage)\cdot(T1\_CO)\ ...\\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_TLEV\_percentage)\cdot(TLEV\_CO)\ ...\\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_LEV\_percentage)\cdot(LEV\_CO)\ ...\\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_ULEV\_percentage)\cdot(ULEV\_CO)\end{array}\right]$$

$$LMM_{CO} = 6.626\times 10^{8}\ gm$$

Emissions Due to Vehicles manufactured 1995 or before:

Note: Prior to 1996 vehicles were generally classified as either Light Duty Vehicles (LDV) or Light Dut Trucks (LDT)

Recalculated Old Vehicle Distributions

$LDV_{old} := SmC_{old} + LMM_{old}$ $\quad LDV_{old} = 0.8$

$LDT_{old} := SUV_{old}$ $\quad LDT_{old} = 0.2$

x100 percent distribution

1992 to 1995 Emissions Data:

By 1992, all vehicles had to conform to the following Federal standard:

$$LDV\_9295_{CO} := 3.4 \cdot \frac{gm}{mi} \qquad LDV\_9295_{HC} := 0.41 \cdot \frac{gm}{mi} \qquad LDV\_9295_{NOx} := 1.0 \cdot \frac{gm}{mi}$$

$$LDT\_9295_{CO} := 10 \cdot \frac{gm}{mi} \qquad LDT\_9295_{HC} := 0.67 \cdot \frac{gm}{mi} \qquad LDT\_9295_{NOx} := 1.2 \cdot \frac{gm}{mi}$$

1982 - 1991 Emissions Data:

In this time frame, HC were not regulated. Instead Volatile Organic Compounds (VOC) were the standard, and will be considered nearly equivalent to HC's

Vehicles older than 1991 have reached their full usefull life of 10 yrs / 100,000 mi

$$LDV\_8291_{CO} := 4.2 \cdot \frac{gm}{mi} \qquad LDV\_8291_{VOC} := 0.80 \cdot \frac{gm}{mi} \qquad LDV\_8291_{NOx} := 1.0 \frac{gm}{mi}$$

$$LDT\_8291_{CO} := \frac{10 \cdot 8 + 18}{9} \cdot \frac{gm}{mi} \qquad LDT\_8291_{VOC} := 0.80 \cdot \frac{gm}{mi} \qquad LDT\_8291_{NOx} := 1.2 \cdot \frac{gm}{mi}$$

Pre 1982 Data:

$$LDV\_P82_{CO} := \frac{23 \cdot 2 + 39 \cdot 3 + 15 \cdot 5}{10} \cdot \frac{gm}{mi} \qquad LDV\_P82_{NOx} := \frac{3 \cdot 3 + 3.1 \cdot 2 + 2 \cdot 4 + 1 \cdot 2}{11} \cdot \frac{gm}{mi}$$

$$LDV\_P82_{VOC} := \frac{3.4 \cdot 3 + 1.5 \cdot 5 + 0.41 \cdot 2}{10} \cdot \frac{gm}{mi}$$

$$LDT\_P82_{CO} := \frac{39 \cdot 3 + 20 \cdot 5 + 18 \cdot 4}{12} \cdot \frac{gm}{mi} \qquad LDT\_P82_{VOC} := \frac{3.4 \cdot 3 + 2 \cdot 4 + 1.7 \cdot 6}{13} \cdot \frac{gm}{mi}$$

$$LDT\_P82_{NOx} := \frac{3 \cdot 3 + 3.1 \cdot 4 + 2.3 \cdot 6}{13} \cdot \frac{gm}{mi}$$

Emissions Calculations:

1992 - 1995

$LDV9295_{CO} := V_{9295} \cdot (Total\_Worcester\_miles) \cdot LDV\_9295_{CO} \cdot LDC\%$ $LDV9295_{CO} = 5.4 \times 10^{8}\ gm$

$LDT9295_{CO} := V_{9295} \cdot (Total\_Worcester\_miles) \cdot LDT\_9295_{CO} \cdot LDT\%$ $LDT9295_{CO} = 3.971 \times 10^{8}\ gm$

$LDV9295_{NOx} := V_{9295} \cdot (Total\_Worcester\_miles) \cdot LDV\_9295_{NOx} \cdot LDC\%$ $LDV9295_{NOx} = 1.588 \times 10^{8}\ gm$

$LDT9295_{NOx} := V_{9295} \cdot (Total\_Worcester\_miles) \cdot LDT\_9295_{NOx} \cdot LDT\%$ $LDT9295_{NOx} = 4.765 \times 10^{7}\ gm$

$LDV9295_{HC} := V_{9295} \cdot (Total\_Worcester\_miles) \cdot LDV\_9295_{HC} \cdot LDC\%$ $LDV9295_{HC} = 6.512 \times 10^{7}\ gm$

$LDT9295_{HC} := V_{9295} \cdot (Total\_Worcester\_miles) \cdot LDT\_9295_{HC} \cdot LDT\%$ $LDT9295_{HC} = 2.66 \times 10^{7}\ gm$

1982-1991

$LDV8291_{CO} := V_{8291} \cdot (Total\_Worcester\_miles) \cdot LDV\_8291_{CO} \cdot LDC\%$ $LDV8291_{CO} = 4.892 \times 10^{8}\ gm$

$LDT8291_{CO} := V_{8291} \cdot (Total\_Worcester\_miles) \cdot LDT\_8291_{CO} \cdot LDT\%$ $LDT8291_{CO} = 3.171 \times 10^{8}\ gm$

$LDV8291_{NOx} := V_{8291} \cdot (Total\_Worcester\_miles) \cdot LDV\_8291_{NOx} \cdot LDC\%$ $LDV8291_{NOx} = 1.165 \times 10^{8}\ gm$

$LDT8291_{NOx} := V_{8291} \cdot (Total\_Worcester\_miles) \cdot LDT\_8291_{NOx} \cdot LDT\%$ $LDT8291_{NOx} = 3.494 \times 10^{7}\ gm$

$LDV8291_{VOC} := V_{8291} \cdot (Total\_Worcester\_miles) \cdot LDV\_8291_{VOC} \cdot LDC\%$ $LDV8291_{VOC} = 9.318 \times 10^{7}\ gm$

$LDT8291_{VOC} := V_{8291} \cdot (Total\_Worcester\_miles) \cdot LDT\_8291_{VOC} \cdot LDT\%$ $LDT8291_{VOC} = 2.33 \times 10^{7}\ gm$

Pre 1982

$LDVP82_{CO} := V_{P82} \cdot (Total\_Worcester\_miles) \cdot LDV\_P82_{CO} \cdot LDC\%$ $LDVP82_{CO} = 3.78 \times 10^{8}\ gm$

$LDTP82_{CO} := V_{P82} \cdot (Total\_Worcester\_miles) \cdot LDT\_P82_{CO} \cdot LDT\%$ $LDTP82_{CO} = 9.563 \times 10^{7}\ gm$

$LDVP82_{NOx} := V_{P82} \cdot (Total\_Worcester\_miles) \cdot LDV\_P82_{NOx} \cdot LDC\%$ $LDVP82_{NOx} = 3.639 \times 10^{7}\ gm$

$LDTP82_{NOx} := V_{P82} \cdot (Total\_Worcester\_miles) \cdot LDT\_P82_{NOx} \cdot LDT\%$ $LDTP82_{NOx} = 1.075 \times 10^{7}\ gm$

$LDVP82_{VOC} := V_{P82} \cdot (Total\_Worcester\_miles) \cdot LDV\_P82_{VOC} \cdot LDC\%$ $LDVP82_{VOC} = 2.942 \times 10^{7}\ gm$

$LDTP82_{VOC} := V_{P82} \cdot (Total\_Worcester\_miles) \cdot LDT\_P82_{VOC} \cdot LDT\%$ $LDTP82_{VOC} = 8.675 \times 10^{6}\ gm$

Total Emissions of New Vehicles, (English Tons):

Carbon Monoxide:

$$CO_{new} := LMM_{CO} + SmC_{CO} + SUV_{CO}$$

$$CO_{new} = 1409\,ton$$

$LMM_{CO} = 730.4\,ton$

$SmC_{CO} = 332.4\,ton$

$SUV_{CO} = 346.1\,ton$

Nitrous Oxides:

$$NOx_{new} := LMM_{NOx} + SmC_{NOx} + SUV_{NOx}$$

$$NOx_{new} = 114.5\,ton$$

$LMM_{NOx} = 53.1\,ton$

$SmC_{NOx} = 26.4\,ton$

$SUV_{NOx} = 35\,ton$

Hydocarbons:

$$HC_{new} := LMM_{HC} + SmC_{HC} + SUV_{HC}$$

$$HC_{new} = 49.7\,ton$$

$LMM_{HC} = 21.4\,ton$

$SmC_{HC} = 11.2\,ton$

$SUV_{HC} = 17.1\,ton$

Total Emissions:

$$Emissions_{new} := CO_{new} + NOx_{new} + HC_{new}$$

$$Emissions_{new} = 1573.2\,ton$$

Total Emissions of Older Vehicles, (English Tons):

Carbon Monoxide:

$LDV9295_{CO} = 595.3\,ton$ $LDV8291_{CO} = 539.3\,ton$ $LDVP82_{CO} = 416.7\,ton$

$LDT9295_{CO} = 437.7\,ton$ $LDT8291_{CO} = 349.5\,ton$ $LDTP82_{CO} = 105.4\,ton$

$$CO_{old} := LDV9295_{CO} + LDT9295_{CO} + LDV8291_{CO} + LDT8291_{CO} \ldots + LDVP82_{CO} + LDTP82_{CO}$$

Nitrous Oxides:

$LDV9295_{NOx} = 175.1\,ton$ $LDV8291_{NOx} = 128.4\,ton$ $LDVP82_{NOx} = 40.1\,ton$

$LDT9295_{NOx} = 52.5\,ton$ $LDT8291_{NOx} = 38.5\,ton$ $LDTP82_{NOx} = 11.9\,ton$

$$NOx_{old} := LDV9295_{NOx} + LDT9295_{NOx} + LDV8291_{NOx} + LDT8291_{NOx} \ldots + LDVP82_{NOx} + LDTP82_{NOx}$$

HydroCarbons and Volatile Organic Compounds:

$LDV9295_{HC} = 71.8\,ton$ $LDV8291_{VOC} = 102.7\,ton$ $LDVP82_{VOC} = 32.4\,ton$

$LDT9295_{HC} = 29.3\,ton$ $LDT8291_{VOC} = 25.7\,ton$ $LDTP82_{VOC} = 9.6\,ton$

$$HC_{old} := LDV9295_{HC} + LDT9295_{HC} + LDV8291_{VOC} + LDT8291_{VOC} \ldots + LDVP82_{VOC} + LDTP82_{VOC}$$

Totals for Older Vehicles:

$CO_{old} = 2443.9\,ton$ $NOx_{old} = 446.5\,ton$ $HC_{old} = 271.5\,ton$

$Emissions_{old} := CO_{old} + NOx_{old} + HC_{old}$

$Emissions_{old} = 3161.9\,ton$

Calculate emissions of a population of 25% SLEV

$Number\_of\_SLEV := (0.25)\cdot\left(V\%_{old}\right)\cdot Worcester\_population\cdot Vehicles\_per\_person$

$Commuter\_miles_{SLEV} := (Travel\_distance)\cdot\left(\frac{2}{day}\right)\cdot(Work\_days)\cdot(Number\_of\_SLEV)$

$Commuter\_miles_{SLEV} = 0.101\,billion\_miles$ driven per year

$Avg\_commuter\_miles_{SLEV} := \frac{Commuter\_miles_{SLE}}{Number\_of\_SLEV}$ $Avg\_commuter\_miles_{SLEV} = 3.654 \times 10^{3}\,mi$ per vehicle driven per year

$Weekend\_miles_{SLEV} := \left(\frac{Travel\_distance}{2}\right)\cdot\left(\frac{2}{day}\right)\cdot(Week\_ends)\cdot(Number\_of\_SLEV)$

$Weekend\_miles_{SLEV} = 20.157\,million\_miles$ driven per year

$Avg\_weekend\_miles_{SLEV} := \frac{Weekend\_miles_{SLEV}}{Number\_of\_SLEV}$ $Avg\_weekend\_miles_{SLEV} = 728\,mi$ per venicle driven per year

$Total\_Worcester\_miles_{SLEV} := Weekend\_miles_{SLEV} + Commuter\_miles_{SLEV}$

$Total\_Worcester\_miles_{SLEV} = 0.121\,billion\_miles$ driven per year

$SLEV_{CO} := Total\_Worcester\_miles_{SLEV}\cdot SLEV\_CO$ $SLEV_{CO} = 133.745\,ton$

$SLEV_{HC} := Total\_Worcester\_miles_{SLEV}\cdot SLEV\_HC$ $SLEV_{HC} = 1.337\,ton$

$SLEV_{NOx} := Total\_Worcester\_miles_{SLEV}\cdot SLEV\_NOx$ $SLEV_{NOx} = 2.675\,ton$

$Total\_Emissions := Emissions_{new} + Emissions_{old} + SLEV_{CO} + SLEV_{HC} + SLEV_{NOx}$

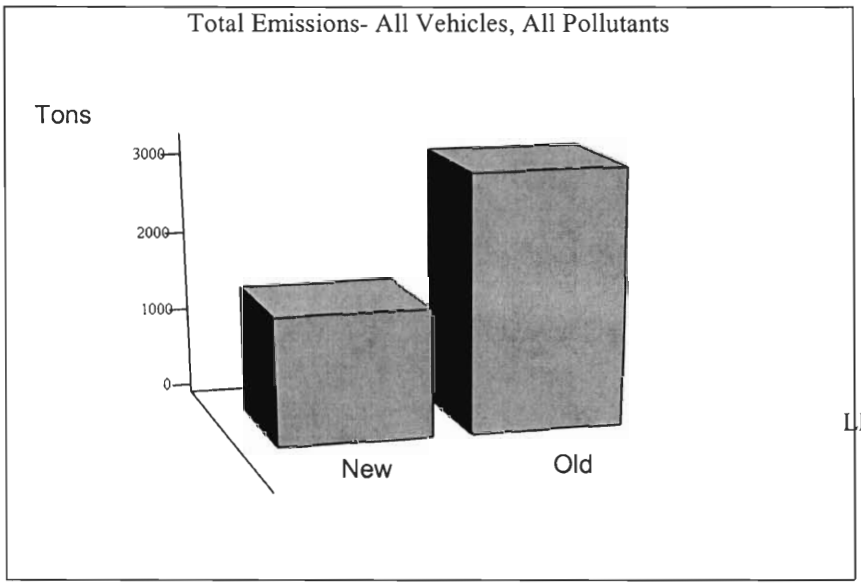
$Total\_Emissions = 4872.8\,ton$

$CO_{Tot} := SLEV_{CO} + CO_{old} + CO_{new}$ $CO_{Tot} = 3986.6\,ton$

$NOx_{Tot} := SLEV_{NOx} + NOx_{old} + NOx_{new}$ $NOx_{Tot} = 563.7\,ton$

$HC_{Tot} := SLEV_{HC} + HC_{old} + HC_{new}$ $HC_{Tot} = 322.6\,ton$

$$Graph1 := \left(\frac{Emissions_{new}}{2000} \quad \frac{Emissions_{old}}{2000} \right)$$



$LDTP82_{VOC} = 12.7$

Replacing 50% of all Vehicles w/Hybrids

billion_miles := $10^9 \cdot mi$

million_miles := $10^6 \cdot mi$

Assumptions:

Vehicles traveling through Worcester Travel an average of 7 miles each

Travel_distance := $7 \cdot mi$

40% of the pollutants in the air come from vehicles

Work_days := $261 \cdot day$

Week_ends := $104 \cdot day$

City Data:

Worcester_population := 254900 people

Vehicles_per_person := 0.79

Percentages of Vehicle Types:

Newer Vehicles:

SUV := 0.275 SmC := 0.21 LMM := 0.51

Older Vehicles:

SUV_{old} := 0.20 SmC_{old} := 0.20 LMM_{old} := 0.60 LDT% := SUV_{old}

LDC% := $SmC_{old} + LMM_{old}$

Age distribution of Vehicles on the Roads:

1996 - 2002 V_{9602} := 0.45

1992 - 1995 V_{9295} := 0.30

1982 - 1991 V_{8291} := 0.22

Pre 1982 V_{P82} := 0.03

Transitional Low Emissions Vehicle Data:

TLEV_NMOG := $0.125 \cdot \frac{gm}{mi}$ TLEV_NOx := $0.4 \cdot \frac{gm}{mi}$

TLEV_CO := $3.4 \cdot \frac{gm}{mi}$ TLEV_HCHO := $0.015 \cdot \frac{gm}{mi}$

TLEV HC := TLEV NMOG + TLEV_HCHO

TLEV_HC = $0.14 \frac{gm}{mi}$

Low Emissions Vehicle Data:

LEV_NMOG := $0.075 \cdot \frac{gm}{mi}$ LEV_NOx := $0.2 \cdot \frac{gm}{mi}$

LEV_CO := $3.4 \cdot \frac{gm}{mi}$ LEV_HCHO := $0.015 \cdot \frac{gm}{mi}$

LEV_HC := LEV_NMOG + LEV_HCHO

LEV_HC = $0.09 \frac{gm}{mi}$

Ultra Low Emissions Vehicle Data:

$$ULEV\_NMOG := 0.04 \cdot \frac{gm}{mi} \qquad ULEV\_NOx := 0.2 \cdot \frac{gm}{mi}$$

$$ULEV\_CO := 1.7 \cdot \frac{gm}{mi} \qquad ULEV\_HCHO := 0.008 \cdot \frac{gm}{mi}$$

$$ULEV\_HC := ULEV\_NMOG + ULEV\_HCHO$$

$$ULEV\_HC = 0.048 \frac{gm}{mi}$$

Super Low Emissions Vehicle Data:

$$SLEV\_CO := 1.0 \cdot \frac{gm}{mi} \qquad SLEV\_HC := 0.01 \cdot \frac{gm}{mi} \qquad SLEV\_NOx := 0.02 \cdot \frac{gm}{mi}$$

Zero Emissions Vehicle Data:

$$ZEV\_CO := 0 \cdot \frac{gm}{mi} \qquad ZEV\_HC := 0 \cdot \frac{gm}{mi} \qquad ZEV\_NOx := 0 \cdot \frac{gm}{mi}$$

Tier 1 Emissions Data:

$$T1\_CO := 4.2 \cdot \frac{gm}{mi} \qquad T1\_HC := 0.31 \cdot \frac{gm}{mi} \qquad T1\_NOx := 0.6 \cdot \frac{gm}{mi}$$

Tabulated Vehicle Distribution for New Vehicles:

$$SUV\_ZEV\_percentage := \frac{0.21}{100} \qquad LMM\_ZEV\_percentage := 0$$

$$SUV\_SLEV\_percentage := \frac{0}{100} \qquad LMM\_SLEV\_percentage := \frac{0}{100}$$

$$SUV\_ULEV\_percentage := \frac{4.5}{100} \qquad LMM\_ULEV\_percentage := \frac{19.13}{100}$$

$$SUV\_LEV\_percentage := \frac{51.82}{100} \qquad LMM\_LEV\_percentage := \frac{70.40}{100}$$

$$SUV\_TLEV\_percentage := \frac{1.5}{100} \qquad LMM\_TLEV\_percentage := \frac{7.94}{100}$$

$$SUV\_T1\_percentage := \frac{41.11}{100} \qquad LMM\_T1\_percentage := \frac{2.17}{100}$$

$$SmC\_ZEV\_percentage := \frac{0.26}{100} \qquad SmC\_LEV\_percentage := \frac{65.17}{100}$$

$$SmC\_SLEV\_percentage := \frac{0}{100} \qquad SmC\_TLEV\_percentage := \frac{9.5}{100}$$

$$SmC\_ULEV\_percentage := \frac{15.04}{100} \qquad SmC\_T1\_percentage := \frac{8.97}{100}$$

Percentages of Each New Vehicle Type Observed on the Road:

SmC_on_road := .2395 LMM_on_road := .5418

SUV_on_road := .2187

Equations:

$$\text{Number\_of\_Vehicles} := 0.5 \cdot \text{Worcester\_population} \cdot \text{Vehicles\_per\_person}$$

$$\text{Number\_of\_Vehicles} = 100686$$

$$\text{Commuter\_miles} := (\text{Travel\_distance}) \cdot \left(\frac{2}{\text{day}}\right) \cdot (\text{Work\_days}) \cdot (\text{Number\_of\_Vehicles})$$

$$\text{Commuter\_miles} = 0.368\,\text{billion\_miles driven per year}$$

$$\text{Avg\_commuter\_miles} := \frac{\text{Commuter\_miles}}{\text{Number\_of\_Vehicles}} \qquad \text{Avg\_commuter\_miles} = 3.654 \times 10^{3}\,\text{mi per vehicle driven per year}$$

$$\text{Weekend\_miles} := \left(\frac{\text{Travel\_distance}}{2}\right) \cdot \left(\frac{2}{\text{day}}\right) \cdot (\text{Week\_ends}) \cdot (\text{Number\_of\_Vehicles})$$

$$\text{Weekend\_miles} = 73.299\,\text{million\_milesdriven per year}$$

$$\text{Avg\_weekend\_miles} := \frac{\text{Weekend\_miles}}{\text{Number\_of\_Vehicles}} \qquad \text{Avg\_weekend\_miles} = 728\,\text{mi per vehicle driven per year}$$

$$\text{Total\_Worcester\_miles} := \text{Weekend\_miles} + \text{Commuter\_miles} \qquad \text{Total\_Worcester\_miles} = 0.441\,\text{billion\_miles driven per year}$$

Emissions Due to New SUV's

$$\text{SUV}_{\text{NOx}} := V_{9602} \cdot \left[\begin{array}{l} (\text{Total\_Worcester\_miles}) \cdot (\text{SUV\_on\_road}) \cdot (\text{SUV\_ZEV\_percentage}) \cdot (\text{ZEV\_NOx}) \ldots \\ + (\text{Total\_Worcester\_miles}) \cdot (\text{SUV\_on\_road}) \cdot (\text{SUV\_SLEV\_percentage}) \cdot (\text{SLEV\_NOx}) \ldots \\ + (\text{Total\_Worcester\_miles}) \cdot (\text{SUV\_on\_road}) \cdot (\text{SUV\_T1\_percentage}) \cdot (\text{T1\_NOx}) \ldots \\ + (\text{Total\_Worcester\_miles}) \cdot (\text{SUV\_on\_road}) \cdot (\text{SUV\_TLEV\_percentage}) \cdot (\text{TLEV\_NOx}) \ldots \\ + (\text{Total\_Worcester\_miles}) \cdot (\text{SUV\_on\_road}) \cdot (\text{SUV\_LEV\_percentage}) \cdot (\text{LEV\_NOx}) \ldots \\ + (\text{Total\_Worcester\_miles}) \cdot (\text{SUV\_on\_road}) \cdot (\text{SUV\_ULEV\_percentage}) \cdot (\text{ULEV\_NOx}) \end{array} \right]$$

$$\text{SUV}_{\text{NOx}} = 1.586 \times 10^{7}\,\text{gm}$$

$$\text{SUV}_{\text{HC}} := V_{9602} \cdot \left[\begin{array}{l} (\text{Total\_Worcester\_miles}) \cdot (\text{SUV\_on\_road}) \cdot (\text{SUV\_ZEV\_percentage}) \cdot (\text{ZEV\_HC}) \ldots \\ + (\text{Total\_Worcester\_miles}) \cdot (\text{SUV\_on\_road}) \cdot (\text{SUV\_SLEV\_percentage}) \cdot (\text{SLEV\_HC}) \ldots \\ + (\text{Total\_Worcester\_miles}) \cdot (\text{SUV\_on\_road}) \cdot (\text{SUV\_T1\_percentage}) \cdot (\text{T1\_HC}) \ldots \\ + (\text{Total\_Worcester\_miles}) \cdot (\text{SUV\_on\_road}) \cdot (\text{SUV\_TLEV\_percentage}) \cdot (\text{TLEV\_HC}) \ldots \\ + (\text{Total\_Worcester\_miles}) \cdot (\text{SUV\_on\_road}) \cdot (\text{SUV\_LEV\_percentage}) \cdot (\text{LEV\_HC}) \ldots \\ + (\text{Total\_Worcester\_miles}) \cdot (\text{SUV\_on\_road}) \cdot (\text{SUV\_ULEV\_percentage}) \cdot (\text{ULEV\_HC}) \end{array} \right]$$

$$\text{SUV}_{\text{HC}} = 7.744 \times 10^{6}\,\text{gm}$$

$$SUV_{CO} := V_{9602}\cdot\left[\begin{array}{l}(Total\_Worcester\_miles)\cdot(SUV\_on\_road)\cdot(SUV\_ZEV\_percentage)\cdot(ZEV\_CO)\ ... \\ +(Total\_Worcester\_miles)\cdot(SUV\_on\_road)\cdot(SUV\_SLEV\_percentage)\cdot(SLEV\_CO)\ ... \\ +(Total\_Worcester\_miles)\cdot(SUV\_on\_road)\cdot(SUV\_T1\_percentage)\cdot(T1\_CO)\ ... \\ +(Total\_Worcester\_miles)\cdot(SUV\_on\_road)\cdot(SUV\_TLEV\_percentage)\cdot(TLEV\_CO)\ ... \\ +(Total\_Worcester\_miles)\cdot(SUV\_on\_road)\cdot(SUV\_LEV\_percentage)\cdot(LEV\_CO)\ ... \\ +(Total\_Worcester\_miles)\cdot(SUV\_on\_road)\cdot(SUV\_ULEV\_percentage)\cdot(ULEV\_CO)\end{array}\right]$$

$$SUV_{CO} = 1.57\times 10^{8}\ gm$$

Emissions Due to New Small Cars

$$SmC_{NOx} := V_{9602}\cdot\left[\begin{array}{l}(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_ZEV\_percentage)\cdot(ZEV\_NOx)\ ... \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_SLEV\_percentage)\cdot(SLEV\_NOx)\ ... \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_T1\_percentage)\cdot(T1\_NOx)\ ... \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_TLEV\_percentage)\cdot(TLEV\_NOx)\ ... \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_LEV\_percentage)\cdot(LEV\_NOx)\ ... \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_ULEV\_percentage)\cdot(ULEV\_NOx)\end{array}\right]$$

$$SmC_{NOx} = 1.199\times 10^{7}\ gm$$

$$SmC_{HC} := V_{9602}\cdot\left[\begin{array}{l}(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_ZEV\_percentage)\cdot(ZEV\_HC)\ ... \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_SLEV\_percentage)\cdot(SLEV\_HC)\ ... \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_T1\_percentage)\cdot(T1\_HC)\ ... \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_TLEV\_percentage)\cdot(TLEV\_HC)\ ... \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_LEV\_percentage)\cdot(LEV\_HC)\ ... \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_ULEV\_percentage)\cdot(ULEV\_HC)\end{array}\right]$$

$$SmC_{HC} = 5.087\times 10^{6}\ gm$$

$$SmC_{CO} := V_{9602}\cdot\left[\begin{array}{l}(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_ZEV\_percentage)\cdot(ZEV\_CO)\ ... \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_SLEV\_percentage)\cdot(SLEV\_CO)\ ... \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_T1\_percentage)\cdot(T1\_CO)\ ... \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_TLEV\_percentage)\cdot(TLEV\_CO)\ ... \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_LEV\_percentage)\cdot(LEV\_CO)\ ... \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_ULEV\_percentage)\cdot(ULEV\_CO)\end{array}\right]$$

$$SmC_{CO} = 1.508\times 10^{8}\ gm$$

Emissions Due to New Large-Medium cars and Minivans

$$LMM_{NOx} := V_{9602}\cdot\left[\begin{array}{l}(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_ZEV\_percentage)\cdot(ZEV\_NOx)\ ... \\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_SLEV\_percentage)\cdot(SLEV\_NOx)\ ... \\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_T1\_percentage)\cdot(T1\_NOx)\ ... \\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_TLEV\_percentage)\cdot(TLEV\_NOx)\ ... \\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_LEV\_percentage)\cdot(LEV\_NOx)\ ... \\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_ULEV\_percentage)\cdot(ULEV\_NOx)\end{array}\right]$$

$$LMM_{NOx} = 2.408 \times 10^{7}\ gm$$

$$LMM_{HC} := V_{9602}\cdot\left[\begin{array}{l}(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_ZEV\_percentage)\cdot(ZEV\_HC)\ ... \\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_SLEV\_percentage)\cdot(SLEV\_HC)\ ... \\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_T1\_percentage)\cdot(T1\_HC)\ ... \\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_TLEV\_percentage)\cdot(TLEV\_HC)\ ... \\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_LEV\_percentage)\cdot(LEV\_HC)\ ... \\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_ULEV\_percentage)\cdot(ULEV\_HC)\end{array}\right]$$

$$LMM_{HC} = 9.723 \times 10^{6}\ gm$$

$$LMM_{CO} := V_{9602}\cdot\left[\begin{array}{l}(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_ZEV\_percentage)\cdot(ZEV\_CO)\ ... \\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_SLEV\_percentage)\cdot(SLEV\_CO)\ ... \\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_T1\_percentage)\cdot(T1\_CO)\ ... \\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_TLEV\_percentage)\cdot(TLEV\_CO)\ ... \\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_LEV\_percentage)\cdot(LEV\_CO)\ ... \\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_ULEV\_percentage)\cdot(ULEV\_CO)\end{array}\right]$$

$$LMM_{CO} = 3.313 \times 10^{8}\ gm$$

Emissions Due to Vehicles manufactured 1995 or before:

Note: Prior to 1996 vehicles were generally classified as either Light Duty Vehicles (LDV) or Light Dut Trucks (LDT)

Recalculated Old Vehicle Distributions

$LDV_{old} := SmC_{old} + LMM_{old}$ $LDV_{old} = 0.8$

$LDT_{old} := SUV_{old}$ $LDT_{old} = 0.2$

x100 percent distribution

1992 to 1995 Emissions Data:

By 1992, all vehicles had to conform to the following Federal standard:

$LDV\_9295_{CO} := 3.4 \cdot \frac{gm}{mi}$ $LDV\_9295_{HC} := 0.41 \cdot \frac{gm}{mi}$ $LDV\_9295_{NOx} := 1.0 \cdot \frac{gm}{mi}$

$LDT\_9295_{CO} := 10 \cdot \frac{gm}{mi}$ $LDT\_9295_{HC} := 0.67 \cdot \frac{gm}{mi}$ $LDT\_9295_{NOx} := 1.2 \cdot \frac{gm}{mi}$

1982 - 1991 Emissions Data:

In this time frame, HC were not regulated. Instead Volatile Organic Compounds (VOC) were the standard, and will be considered nearly equivalent to HC's

Vehicles older than 1991 have reached their full usefull life of 10 yrs / 100,000 mi

$LDV\_8291_{CO} := 4.2 \cdot \frac{gm}{mi}$ $LDV\_8291_{VOC} := 0.80 \cdot \frac{gm}{mi}$ $LDV\_8291_{NOx} := 1.0 \frac{gm}{mi}$

$LDT\_8291_{CO} := \frac{10 \cdot 8 + 18}{9} \cdot \frac{gm}{mi}$ $LDT\_8291_{VOC} := 0.80 \cdot \frac{gm}{mi}$ $LDT\_8291_{NOx} := 1.2 \cdot \frac{gm}{mi}$

Pre 1982 Data:

$LDV\_P82_{CO} := \frac{23 \cdot 2 + 39 \cdot 3 + 15 \cdot 5}{10} \cdot \frac{gm}{mi}$ $LDV\_P82_{NOx} := \frac{3 \cdot 3 + 3.1 \cdot 2 + 2 \cdot 4 + 1 \cdot 2}{11} \cdot \frac{gm}{mi}$

$LDV\_P82_{VOC} := \frac{3.4 \cdot 3 + 1.5 \cdot 5 + 0.41 \cdot 2}{10} \cdot \frac{gm}{mi}$

$LDT\_P82_{CO} := \frac{39 \cdot 3 + 20 \cdot 5 + 18 \cdot 4}{12} \cdot \frac{gm}{mi}$ $LDT\_P82_{VOC} := \frac{3.4 \cdot 3 + 2 \cdot 4 + 1.7 \cdot 6}{13} \cdot \frac{gm}{mi}$

$LDT\_P82_{NOx} := \frac{3 \cdot 3 + 3.1 \cdot 4 + 2.3 \cdot 6}{13} \cdot \frac{gm}{mi}$

Emissions Calculations:

1992 - 1995

$LDV9295_{CO} := V_{9295} \cdot (Total\_Worcester\_miles) \cdot LDV\_9295_{CO} \cdot LDC\%$ $LDV9295_{CO} = 3.6 \times 10^{8}\ gm$

$LDT9295_{CO} := V_{9295} \cdot (Total\_Worcester\_miles) \cdot LDT\_9295_{CO} \cdot LDT\%$ $LDT9295_{CO} = 2.647 \times 10^{8}\ gm$

$LDV9295_{NOx} := V_{9295} \cdot (Total\_Worcester\_miles) \cdot LDV\_9295_{NOx} \cdot LDC\%$ $LDV9295_{NOx} = 1.059 \times 10^{8}\ gm$

$LDT9295_{NOx} := V_{9295} \cdot (Total\_Worcester\_miles) \cdot LDT\_9295_{NOx} \cdot LDT\%$ $LDT9295_{NOx} = 3.177 \times 10^{7}\ gm$

$LDV9295_{HC} := V_{9295} \cdot (Total\_Worcester\_miles) \cdot LDV\_9295_{HC} \cdot LDC\%$ $LDV9295_{HC} = 4.341 \times 10^{7}\ gm$

$LDT9295_{HC} := V_{9295} \cdot (Total\_Worcester\_miles) \cdot LDT\_9295_{HC} \cdot LDT\%$ $LDT9295_{HC} = 1.774 \times 10^{7}\ gm$

1982-1991

$LDV8291_{CO} := V_{8291} \cdot (Total\_Worcester\_miles) \cdot LDV\_8291_{CO} \cdot LDC\%$ $LDV8291_{CO} = 3.261 \times 10^{8}\ gm$

$LDT8291_{CO} := V_{8291} \cdot (Total\_Worcester\_miles) \cdot LDT\_8291_{CO} \cdot LDT\%$ $LDT8291_{CO} = 2.114 \times 10^{8}\ gm$

$LDV8291_{NOx} := V_{8291} \cdot (Total\_Worcester\_miles) \cdot LDV\_8291_{NOx} \cdot LDC\%$ $LDV8291_{NOx} = 7.765 \times 10^{7}\ gm$

$LDT8291_{NOx} := V_{8291} \cdot (Total\_Worcester\_miles) \cdot LDT\_8291_{NOx} \cdot LDT\%$ $LDT8291_{NOx} = 2.33 \times 10^{7}\ gm$

$LDV8291_{VOC} := V_{8291} \cdot (Total\_Worcester\_miles) \cdot LDV\_8291_{VOC} \cdot LDC\%$ $LDV8291_{VOC} = 6.212 \times 10^{7}\ gm$

$LDT8291_{VOC} := V_{8291} \cdot (Total\_Worcester\_miles) \cdot LDT\_8291_{VOC} \cdot LDT\%$ $LDT8291_{VOC} = 1.553 \times 10^{7}\ gm$

Pre 1982

$LDVP82_{CO} := V_{P82} \cdot (Total\_Worcester\_miles) \cdot LDV\_P82_{CO} \cdot LDC\%$ $LDVP82_{CO} = 2.52 \times 10^{8}\ gm$

$LDTP82_{CO} := V_{P82} \cdot (Total\_Worcester\_miles) \cdot LDT\_P82_{CO} \cdot LDT\%$ $LDTP82_{CO} = 6.375 \times 10^{7}\ gm$

$LDVP82_{NOx} := V_{P82} \cdot (Total\_Worcester\_miles) \cdot LDV\_P82_{NOx} \cdot LDC\%$ $LDVP82_{NOx} = 2.426 \times 10^{7}\ gm$

$LDTP82_{NOx} := V_{P82} \cdot (Total\_Worcester\_miles) \cdot LDT\_P82_{NOx} \cdot LDT\%$ $LDTP82_{NOx} = 7.168 \times 10^{6}\ gm$

$LDVP82_{VOC} := V_{P82} \cdot (Total\_Worcester\_miles) \cdot LDV\_P82_{VOC} \cdot LDC\%$ $LDVP82_{VOC} = 1.961 \times 10^{7}\ gm$

$LDTP82_{VOC} := V_{P82} \cdot (Total\_Worcester\_miles) \cdot LDT\_P82_{VOC} \cdot LDT\%$ $LDTP82_{VOC} = 5.783 \times 10^{6}\ gm$

Total Emissions of New Vehicles, (English Tons):

Carbon Monoxide:

$$CO_{new} := LMM_{CO} + SmC_{CO} + SUV_{CO}$$

$$CO_{new} = 704.5\,ton$$

$LMM_{CO} = 365.2\,ton$

$SmC_{CO} = 166.2\,ton$

$SUV_{CO} = 173.1\,ton$

Nitrous Oxides:

$$NOx_{new} := LMM_{NOx} + SmC_{NOx} + SUV_{NOx}$$

$$NOx_{new} = 57.2\,ton$$

$LMM_{NOx} = 26.5\,ton$

$SmC_{NOx} = 13.2\,ton$

$SUV_{NOx} = 17.5\,ton$

Hydocarbons:

$$HC_{new} := LMM_{HC} + SmC_{HC} + SUV_{HC}$$

$$HC_{new} = 24.9\,ton$$

$LMM_{HC} = 10.7\,ton$

$SmC_{HC} = 5.6\,ton$

$SUV_{HC} = 8.5\,ton$

Total Emissions:

$$Emissions_{new} := CO_{new} + NOx_{new} + HC_{new}$$

$$Emissions_{new} = 786.6\,ton$$

Total Emissions of Older Vehicles, (English Tons):

Carbon Monoxide:

$LDV9295_{CO} = 396.9\,ton$ $LDV8291_{CO} = 359.5\,ton$ $LDVP82_{CO} = 277.8\,ton$

$LDT9295_{CO} = 291.8\,ton$ $LDT8291_{CO} = 233\,ton$ $LDTP82_{CO} = 70.3\,ton$

$$CO_{old} := LDV9295_{CO} + LDT9295_{CO} + LDV8291_{CO} + LDT8291_{CO} \ldots + LDVP82_{CO} + LDTP82_{CO}$$

Nitrous Oxides:

$LDV9295_{NOx} = 116.7\,ton$ $LDV8291_{NOx} = 85.6\,ton$ $LDVP82_{NOx} = 26.7\,ton$

$LDT9295_{NOx} = 35\,ton$ $LDT8291_{NOx} = 25.7\,ton$ $LDTP82_{NOx} = 7.9\,ton$

$$NOx_{old} := LDV9295_{NOx} + LDT9295_{NOx} + LDV8291_{NOx} + LDT8291_{NOx} \ldots + LDVP82_{NOx} + LDTP82_{NOx}$$

HydroCarbons and Volatile Organic Compounds:

$LDV9295_{HC} = 47.9\,ton$ $LDV8291_{VOC} = 68.5\,ton$ $LDVP82_{VOC} = 21.6\,ton$

$LDT9295_{HC} = 19.6\,ton$ $LDT8291_{VOC} = 17.1\,ton$ $LDTP82_{VOC} = 6.4\,ton$

$$HC_{old} := LDV9295_{HC} + LDT9295_{HC} + LDV8291_{VOC} + LDT8291_{VOC} \ldots + LDVP82_{VOC} + LDTP82_{VOC}$$

Totals for Older Vehicles:

$CO_{old} = 1629.3\,ton$ $NOx_{old} = 297.7\,ton$ $HC_{old} = 181\,ton$

$Emissions_{old} := CO_{old} + NOx_{old} + HC_{old}$

$Emissions_{old} = 2107.9\,ton$

Calculate emissions of a population of 25% SLEV

$Number\_of\_SLEV := 0.5 \cdot Worcester\_population \cdot Vehicles\_per\_person$

$Commuter\_miles_{SLEV} := (Travel\_distance) \cdot \left(\frac{2}{day}\right) \cdot (Work\_days) \cdot (Number\_of\_SLEV)$

$Commuter\_miles_{SLEV} = 0.368\,billion\_miles$ driven per year

$Avg\_commuter\_miles_{SLEV} := \frac{Commuter\_miles_{SLE}}{Number\_of\_SLEV}$ $Avg\_commuter\_miles_{SLEV} = 3.654 \times 10^{3}\,mi$ per vehicle driven per year

$Weekend\_miles_{SLEV} := \left(\frac{Travel\_distance}{2}\right) \cdot \left(\frac{2}{day}\right) \cdot (Week\_ends) \cdot (Number\_of\_SLEV)$

$Weekend\_miles_{SLEV} = 73.299\,million\_miles$ driven per year

$Avg\_weekend\_miles_{SLEV} := \frac{Weekend\_miles_{SLEV}}{Number\_of\_SLEV}$ $Avg\_weekend\_miles_{SLEV} = 728\,mi$ per venicle driven per year

$Total\_Worcester\_miles_{SLEV} := Weekend\_miles_{SLEV} + Commuter\_miles_{SLEV}$

$Total\_Worcester\_miles_{SLEV} = 0.441\,billion\_miles$ driven per year

$SLEV_{CO} := Total\_Worcester\_miles_{SLEV} \cdot SLEV\_CO$ $SLEV_{CO} = 486.344\,ton$

$SLEV_{HC} := Total\_Worcester\_miles_{SLEV} \cdot SLEV\_HC$ $SLEV_{HC} = 4.863\,ton$

$SLEV_{NOx} := Total\_Worcester\_miles_{SLEV} \cdot SLEV\_NOx$ $SLEV_{NOx} = 9.727\,ton$

$Total\_Emissions := Emissions_{new} + Emissions_{old} + SLEV_{CO} + SLEV_{HC} + SLEV_{NOx}$

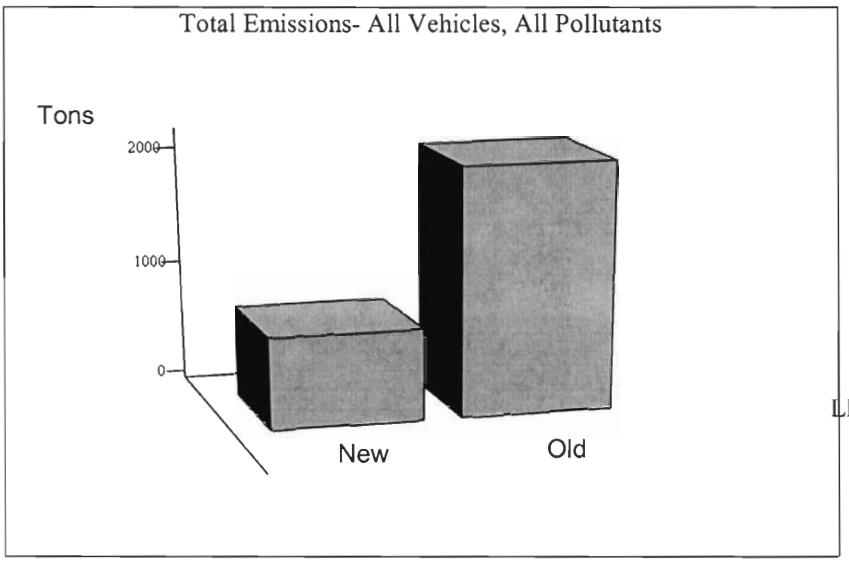
$Total\_Emissions = 3395.4\,ton$

$CO_{Tot} := SLEV_{CO} + CO_{old} + CO_{new}$ $CO_{Tot} = 2820.1\,ton$

$NOx_{Tot} := SLEV_{NOx} + NOx_{old} + NOx_{new}$ $NOx_{Tot} = 364.631\,ton$

$HC_{Tot} := SLEV_{HC} + HC_{old} + HC_{new}$ $HC_{Tot} = 210.72\,ton$

$$Graph1 := \left(\frac{Emissions_{new}}{2000} \quad \frac{Emissions_{old}}{2000} \right)$$



$LDTP82_{VOC} = 12.7\,ton$

Replacing 50% of all new Vehicles w/Hybrids

billion_miles := $10^9 \cdot mi$

million_miles := $10^6 \cdot mi$

Assumptions:

Vehicles traveling through Worcester Travel an average of 7 miles each

Travel_distance := $7 \cdot mi$

Work_days := $261 \cdot day$

Week_ends := $104 \cdot day$

City Data:

Worcester_population := 254900 people

Vehicles_per_person := 0.79

Percentages of Vehicle Types:

Newer Vehicles:

SUV := 0.275 SmC := 0.21 LMM := 0.51

Older Vehicles:

SUV_{old} := 0.20 SmC_{old} := 0.20 LMM_{old} := 0.60 LDT% := SUV_{old}

LDC% := $SmC_{old} + LMM_{old}$

Age distribution of Vehicles on the Roads:

1996 - 2002 $V_{9602} := 0.45 \cdot (0.5)$

1992 - 1995 $V_{9295} := 0.30$

1982 - 1991 $V_{8291} := 0.22$

Pre 1982 $V_{P82} := 0.03$

$V\%_{new} := 0.45$

$V\%_{old} := 0.55$ 55% of all worcester vehicles are "old"

Transitional Low Emissions Vehicle Data:

TLEV_NMOG := $0.125 \cdot \frac{gm}{mi}$ TLEV_NOx := $0.4 \cdot \frac{gm}{mi}$

TLEV_CO := $3.4 \cdot \frac{gm}{mi}$ TLEV_HCHO := $0.015 \cdot \frac{gm}{mi}$

TLEV_HC := TLEV_NMOG + TLEV_HCHO

TLEV_HC = $0.14 \frac{gm}{mi}$

Low Emissions Vehicle Data:

LEV_NMOG := $0.075 \cdot \frac{gm}{mi}$ LEV_NOx := $0.2 \cdot \frac{gm}{mi}$

LEV_CO := $3.4 \cdot \frac{gm}{mi}$ LEV_HCHO := $0.015 \cdot \frac{gm}{mi}$

LEV_HC := LEV_NMOG + LEV_HCHO

LEV_HC = $0.09 \frac{gm}{mi}$

Ultra Low Emissions Vehicle Data:

$$ULEV\_NMOG := 0.04 \cdot \frac{gm}{mi} \qquad ULEV\_NOx := 0.2 \cdot \frac{gm}{mi}$$

$$ULEV\_CO := 1.7 \cdot \frac{gm}{mi} \qquad ULEV\_HCHO := 0.008 \cdot \frac{gm}{mi}$$

$$ULEV\_HC := ULEV\_NMOG + ULEV\_HCHO$$

$$ULEV\_HC = 0.048 \frac{gm}{mi}$$

Super Low Emissions Vehicle Data:

$$SLEV\_CO := 1.0 \cdot \frac{gm}{mi} \qquad SLEV\_HC := 0.01 \cdot \frac{gm}{mi} \qquad SLEV\_NOx := 0.02 \cdot \frac{gm}{mi}$$

Zero Emissions Vehicle Data:

$$ZEV\_CO := 0 \cdot \frac{gm}{mi} \qquad ZEV\_HC := 0 \cdot \frac{gm}{mi} \qquad ZEV\_NOx := 0 \cdot \frac{gm}{mi}$$

Tier 1 Emissions Data:

$$T1\_CO := 4.2 \cdot \frac{gm}{mi} \qquad T1\_HC := 0.31 \cdot \frac{gm}{mi} \qquad T1\_NOx := 0.6 \cdot \frac{gm}{mi}$$

Tabulated Vehicle Distribution for New Vehicles:

$$SUV\_ZEV\_percentage := \frac{0.21}{100} \qquad LMM\_ZEV\_percentage := 0$$

$$SUV\_SLEV\_percentage := \frac{0}{100} \qquad LMM\_SLEV\_percentage := \frac{0}{100}$$

$$SUV\_ULEV\_percentage := \frac{4.5}{100} \qquad LMM\_ULEV\_percentage := \frac{19.13}{100}$$

$$SUV\_LEV\_percentage := \frac{51.82}{100} \qquad LMM\_LEV\_percentage := \frac{70.40}{100}$$

$$SUV\_TLEV\_percentage := \frac{1.5}{100} \qquad LMM\_TLEV\_percentage := \frac{7.94}{100}$$

$$SUV\_T1\_percentage := \frac{41.11}{100} \qquad LMM\_T1\_percentage := \frac{2.17}{100}$$

$$SmC\_ZEV\_percentage := \frac{0.26}{100} \qquad SmC\_LEV\_percentage := \frac{65.17}{100}$$

$$SmC\_SLEV\_percentage := \frac{0}{100} \qquad SmC\_TLEV\_percentage := \frac{9.5}{100}$$

$$SmC\_ULEV\_percentage := \frac{15.04}{100} \qquad SmC\_T1\_percentage := \frac{8.97}{100}$$

Percentages of Each New Vehicle Type Observed on the Road:

SmC_on_road := .2395 LMM_on_road := .5418

SUV_on_road := .2187

Equations:

Number_of_Vehicles := 1.0·Worcester_population·Vehicles_per_person

Number_of_Vehicles = 201371

$$\text{Commuter\_miles} := (\text{Travel\_distance})\cdot\left(\frac{2}{\text{day}}\right)\cdot(\text{Work\_days})\cdot(\text{Number\_of\_Vehicles})$$

Commuter_miles = 0.736 billion_miles driven per year

$$\text{Avg\_commuter\_miles} := \frac{\text{Commuter\_miles}}{\text{Number\_of\_Vehicles}} \qquad \text{Avg\_commuter\_miles} = 3.654\times 10^{3}\ \frac{\text{mi}}{\text{per vehicle driven per year}}$$

$$\text{Weekend\_miles} := \left(\frac{\text{Travel\_distance}}{2}\right)\cdot\left(\frac{2}{\text{day}}\right)\cdot(\text{Week\_ends})\cdot(\text{Number\_of\_Vehicles})$$

Weekend_miles = 146.598 million_milesriven per year

$$\text{Avg\_weekend\_miles} := \frac{\text{Weekend\_miles}}{\text{Number\_of\_Vehicles}} \qquad \text{Avg\_weekend\_miles} = 728\ \frac{\text{mi}}{\text{per vehicle driven per year}}$$

Total_Worcester_miles := Weekend_miles + Commuter_miles Total_Worcester_miles = 0.882 billion_miles driven per year

Emissions Due to New SUV's

$$\text{SUV}_{\text{NOx}} := V_{9602}\cdot\left[\begin{array}{l}(\text{Total\_Worcester\_miles})\cdot(\text{SUV\_on\_road})\cdot(\text{SUV\_ZEV\_percentage})\cdot(\text{ZEV\_NOx})\ \ldots\\ +(\text{Total\_Worcester\_miles})\cdot(\text{SUV\_on\_road})\cdot(\text{SUV\_SLEV\_percentage})\cdot(\text{SLEV\_NOx})\ \ldots\\ +(\text{Total\_Worcester\_miles})\cdot(\text{SUV\_on\_road})\cdot(\text{SUV\_T1\_percentage})\cdot(\text{T1\_NOx})\ \ldots\\ +(\text{Total\_Worcester\_miles})\cdot(\text{SUV\_on\_road})\cdot(\text{SUV\_TLEV\_percentage})\cdot(\text{TLEV\_NOx})\ \ldots\\ +(\text{Total\_Worcester\_miles})\cdot(\text{SUV\_on\_road})\cdot(\text{SUV\_LEV\_percentage})\cdot(\text{LEV\_NOx})\ \ldots\\ +(\text{Total\_Worcester\_miles})\cdot(\text{SUV\_on\_road})\cdot(\text{SUV\_ULEV\_percentage})\cdot(\text{ULEV\_NOx})\end{array}\right]$$

$$\text{SUV}_{\text{NOx}} = 1.586\times 10^{7}\ \text{gm}$$

$$\text{SUV}_{\text{HC}} := V_{9602}\cdot\left[\begin{array}{l}(\text{Total\_Worcester\_miles})\cdot(\text{SUV\_on\_road})\cdot(\text{SUV\_ZEV\_percentage})\cdot(\text{ZEV\_HC})\ \ldots\\ +(\text{Total\_Worcester\_miles})\cdot(\text{SUV\_on\_road})\cdot(\text{SUV\_SLEV\_percentage})\cdot(\text{SLEV\_HC})\ \ldots\\ +(\text{Total\_Worcester\_miles})\cdot(\text{SUV\_on\_road})\cdot(\text{SUV\_T1\_percentage})\cdot(\text{T1\_HC})\ \ldots\\ +(\text{Total\_Worcester\_miles})\cdot(\text{SUV\_on\_road})\cdot(\text{SUV\_TLEV\_percentage})\cdot(\text{TLEV\_HC})\ \ldots\\ +(\text{Total\_Worcester\_miles})\cdot(\text{SUV\_on\_road})\cdot(\text{SUV\_LEV\_percentage})\cdot(\text{LEV\_HC})\ \ldots\\ +(\text{Total\_Worcester\_miles})\cdot(\text{SUV\_on\_road})\cdot(\text{SUV\_ULEV\_percentage})\cdot(\text{ULEV\_HC})\end{array}\right]$$

$$\text{SUV}_{\text{HC}} = 7.744\times 10^{6}\ \text{gm}$$

$$SUV_{CO} := V_{9602}\cdot\left[\begin{array}{l}(Total\_Worcester\_miles)\cdot(SUV\_on\_road)\cdot(SUV\_ZEV\_percentage)\cdot(ZEV\_CO)\ ... \\ +(Total\_Worcester\_miles)\cdot(SUV\_on\_road)\cdot(SUV\_SLEV\_percentage)\cdot(SLEV\_CO)\ ... \\ +(Total\_Worcester\_miles)\cdot(SUV\_on\_road)\cdot(SUV\_T1\_percentage)\cdot(T1\_CO)\ ... \\ +(Total\_Worcester\_miles)\cdot(SUV\_on\_road)\cdot(SUV\_TLEV\_percentage)\cdot(TLEV\_CO)\ ... \\ +(Total\_Worcester\_miles)\cdot(SUV\_on\_road)\cdot(SUV\_LEV\_percentage)\cdot(LEV\_CO)\ ... \\ +(Total\_Worcester\_miles)\cdot(SUV\_on\_road)\cdot(SUV\_ULEV\_percentage)\cdot(ULEV\_CO)\end{array}\right]$$

$$SUV_{CO} = 1.57\times 10^{8}\ gm$$

Emissions Due to New Small Cars

$$SmC_{NOx} := V_{9602}\cdot\left[\begin{array}{l}(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_ZEV\_percentage)\cdot(ZEV\_NOx)\ ... \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_SLEV\_percentage)\cdot(SLEV\_NOx)\ ... \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_T1\_percentage)\cdot(T1\_NOx)\ ... \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_TLEV\_percentage)\cdot(TLEV\_NOx)\ ... \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_LEV\_percentage)\cdot(LEV\_NOx)\ ... \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_ULEV\_percentage)\cdot(ULEV\_NOx)\end{array}\right]$$

$$SmC_{NOx} = 1.199\times 10^{7}\ gm$$

$$SmC_{HC} := V_{9602}\cdot\left[\begin{array}{l}(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_ZEV\_percentage)\cdot(ZEV\_HC)\ ... \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_SLEV\_percentage)\cdot(SLEV\_HC)\ ... \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_T1\_percentage)\cdot(T1\_HC)\ ... \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_TLEV\_percentage)\cdot(TLEV\_HC)\ ... \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_LEV\_percentage)\cdot(LEV\_HC)\ ... \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_ULEV\_percentage)\cdot(ULEV\_HC)\end{array}\right]$$

$$SmC_{HC} = 5.087\times 10^{6}\ gm$$

$$SmC_{CO} := V_{9602}\cdot\left[\begin{array}{l}(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_ZEV\_percentage)\cdot(ZEV\_CO)\ ... \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_SLEV\_percentage)\cdot(SLEV\_CO)\ ... \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_T1\_percentage)\cdot(T1\_CO)\ ... \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_TLEV\_percentage)\cdot(TLEV\_CO)\ ... \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_LEV\_percentage)\cdot(LEV\_CO)\ ... \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_ULEV\_percentage)\cdot(ULEV\_CO)\end{array}\right]$$

$$SmC_{CO} = 1.508\times 10^{8}\ gm$$

Emissions Due to New Large-Medium cars and Minivans

$$LMM_{NOx} := V_{9602}\cdot\left[\begin{array}{l}(\text{Total\_Worcester\_miles})\cdot(\text{LMM\_on\_road})\cdot(\text{LMM\_ZEV\_percentage})\cdot(\text{ZEV\_NOx})\ \ldots\\ +(\text{Total\_Worcester\_miles})\cdot(\text{LMM\_on\_road})\cdot(\text{LMM\_SLEV\_percentage})\cdot(\text{SLEV\_NOx})\ \ldots\\ +(\text{Total\_Worcester\_miles})\cdot(\text{LMM\_on\_road})\cdot(\text{LMM\_T1\_percentage})\cdot(\text{T1\_NOx})\ \ldots\\ +(\text{Total\_Worcester\_miles})\cdot(\text{LMM\_on\_road})\cdot(\text{LMM\_TLEV\_percentage})\cdot(\text{TLEV\_NOx})\ \ldots\\ +(\text{Total\_Worcester\_miles})\cdot(\text{LMM\_on\_road})\cdot(\text{LMM\_LEV\_percentage})\cdot(\text{LEV\_NOx})\ \ldots\\ +(\text{Total\_Worcester\_miles})\cdot(\text{LMM\_on\_road})\cdot(\text{LMM\_ULEV\_percentage})\cdot(\text{ULEV\_NOx})\end{array}\right]$$

$$LMM_{NOx} = 2.408\times 10^{7}\,\text{gm}$$

$$LMM_{HC} := V_{9602}\cdot\left[\begin{array}{l}(\text{Total\_Worcester\_miles})\cdot(\text{LMM\_on\_road})\cdot(\text{LMM\_ZEV\_percentage})\cdot(\text{ZEV\_HC})\ \ldots\\ +(\text{Total\_Worcester\_miles})\cdot(\text{LMM\_on\_road})\cdot(\text{LMM\_SLEV\_percentage})\cdot(\text{SLEV\_HC})\ \ldots\\ +(\text{Total\_Worcester\_miles})\cdot(\text{LMM\_on\_road})\cdot(\text{LMM\_T1\_percentage})\cdot(\text{T1\_HC})\ \ldots\\ +(\text{Total\_Worcester\_miles})\cdot(\text{LMM\_on\_road})\cdot(\text{LMM\_TLEV\_percentage})\cdot(\text{TLEV\_HC})\ \ldots\\ +(\text{Total\_Worcester\_miles})\cdot(\text{LMM\_on\_road})\cdot(\text{LMM\_LEV\_percentage})\cdot(\text{LEV\_HC})\ \ldots\\ +(\text{Total\_Worcester\_miles})\cdot(\text{LMM\_on\_road})\cdot(\text{LMM\_ULEV\_percentage})\cdot(\text{ULEV\_HC})\end{array}\right]$$

$$LMM_{HC} = 9.723\times 10^{6}\,\text{gm}$$

$$LMM_{CO} := V_{9602}\cdot\left[\begin{array}{l}(\text{Total\_Worcester\_miles})\cdot(\text{LMM\_on\_road})\cdot(\text{LMM\_ZEV\_percentage})\cdot(\text{ZEV\_CO})\ \ldots\\ +(\text{Total\_Worcester\_miles})\cdot(\text{LMM\_on\_road})\cdot(\text{LMM\_SLEV\_percentage})\cdot(\text{SLEV\_CO})\ \ldots\\ +(\text{Total\_Worcester\_miles})\cdot(\text{LMM\_on\_road})\cdot(\text{LMM\_T1\_percentage})\cdot(\text{T1\_CO})\ \ldots\\ +(\text{Total\_Worcester\_miles})\cdot(\text{LMM\_on\_road})\cdot(\text{LMM\_TLEV\_percentage})\cdot(\text{TLEV\_CO})\ \ldots\\ +(\text{Total\_Worcester\_miles})\cdot(\text{LMM\_on\_road})\cdot(\text{LMM\_LEV\_percentage})\cdot(\text{LEV\_CO})\ \ldots\\ +(\text{Total\_Worcester\_miles})\cdot(\text{LMM\_on\_road})\cdot(\text{LMM\_ULEV\_percentage})\cdot(\text{ULEV\_CO})\end{array}\right]$$

$$LMM_{CO} = 3.313\times 10^{8}\,\text{gm}$$

Emissions Due to Vehicles manufactured 1995 or before:

Note: Prior to 1996 vehicles were generally classified as either Light Duty Vehicles (LDV) or Light Dut Trucks (LDT)

Recalculated Old Vehicle Distributions

$LDV_{old} := SmC_{old} + LMM_{old}$ $LDV_{old} = 0.8$

$LDT_{old} := SUV_{old}$ $LDT_{old} = 0.2$

x100 percent distribution

1992 to 1995 Emissions Data:

By 1992, all vehicles had to conform to the following Federal standard:

$LDV\_9295_{CO} := 3.4 \cdot \frac{gm}{mi}$ $LDV\_9295_{HC} := 0.41 \cdot \frac{gm}{mi}$ $LDV\_9295_{NOx} := 1.0 \cdot \frac{gm}{mi}$

$LDT\_9295_{CO} := 10 \cdot \frac{gm}{mi}$ $LDT\_9295_{HC} := 0.67 \cdot \frac{gm}{mi}$ $LDT\_9295_{NOx} := 1.2 \cdot \frac{gm}{mi}$

1982 - 1991 Emissions Data:

In this time frame, HC were not regulated. Instead Volatile Organic Compounds (VOC) were the standard, and will be considered nearly equivalent to HC's

Vehicles older than 1991 have reached their full usefull life of 10 yrs / 100,000 mi

$LDV\_8291_{CO} := 4.2 \cdot \frac{gm}{mi}$ $LDV\_8291_{VOC} := 0.80 \cdot \frac{gm}{mi}$ $LDV\_8291_{NOx} := 1.0 \frac{gm}{mi}$

$LDT\_8291_{CO} := \frac{10 \cdot 8 + 18}{9} \cdot \frac{gm}{mi}$ $LDT\_8291_{VOC} := 0.80 \cdot \frac{gm}{mi}$ $LDT\_8291_{NOx} := 1.2 \cdot \frac{gm}{mi}$

Pre 1982 Data:

$LDV\_P82_{CO} := \frac{23 \cdot 2 + 39 \cdot 3 + 15 \cdot 5}{10} \cdot \frac{gm}{mi}$ $LDV\_P82_{NOx} := \frac{3 \cdot 3 + 3.1 \cdot 2 + 2 \cdot 4 + 1 \cdot 2}{11} \cdot \frac{gm}{mi}$

$LDV\_P82_{VOC} := \frac{3.4 \cdot 3 + 1.5 \cdot 5 + 0.41 \cdot 2}{10} \cdot \frac{gm}{mi}$

$LDT\_P82_{CO} := \frac{39 \cdot 3 + 20 \cdot 5 + 18 \cdot 4}{12} \cdot \frac{gm}{mi}$ $LDT\_P82_{VOC} := \frac{3.4 \cdot 3 + 2 \cdot 4 + 1.7 \cdot 6}{13} \cdot \frac{gm}{mi}$

$LDT\_P82_{NOx} := \frac{3 \cdot 3 + 3.1 \cdot 4 + 2.3 \cdot 6}{13} \cdot \frac{gm}{mi}$

Emissions Calculations:

1992 - 1995

$LDV9295_{CO} := V_{9295} \cdot (Total\_Worcester\_miles) \cdot LDV\_9295_{CO} \cdot LDC\%$ $LDV9295_{CO} = 7.2 \times 10^{8}\ gm$

$LDT9295_{CO} := V_{9295} \cdot (Total\_Worcester\_miles) \cdot LDT\_9295_{CO} \cdot LDT\%$ $LDT9295_{CO} = 5.294 \times 10^{8}\ gm$

$LDV9295_{NOx} := V_{9295} \cdot (Total\_Worcester\_miles) \cdot LDV\_9295_{NOx} \cdot LDC\%$ $LDV9295_{NOx} = 2.118 \times 10^{8}\ gm$

$LDT9295_{NOx} := V_{9295} \cdot (Total\_Worcester\_miles) \cdot LDT\_9295_{NOx} \cdot LDT\%$ $LDT9295_{NOx} = 6.353 \times 10^{7}\ gm$

$LDV9295_{HC} := V_{9295} \cdot (Total\_Worcester\_miles) \cdot LDV\_9295_{HC} \cdot LDC\%$ $LDV9295_{HC} = 8.683 \times 10^{7}\ gm$

$LDT9295_{HC} := V_{9295} \cdot (Total\_Worcester\_miles) \cdot LDT\_9295_{HC} \cdot LDT\%$ $LDT9295_{HC} = 3.547 \times 10^{7}\ gm$

1982-1991

$LDV8291_{CO} := V_{8291} \cdot (Total\_Worcester\_miles) \cdot LDV\_8291_{CO} \cdot LDC\%$ $LDV8291_{CO} = 6.523 \times 10^{8}\ gm$

$LDT8291_{CO} := V_{8291} \cdot (Total\_Worcester\_miles) \cdot LDT\_8291_{CO} \cdot LDT\%$ $LDT8291_{CO} = 4.228 \times 10^{8}\ gm$

$LDV8291_{NOx} := V_{8291} \cdot (Total\_Worcester\_miles) \cdot LDV\_8291_{NOx} \cdot LDC\%$ $LDV8291_{NOx} = 1.553 \times 10^{8}\ gm$

$LDT8291_{NOx} := V_{8291} \cdot (Total\_Worcester\_miles) \cdot LDT\_8291_{NOx} \cdot LDT\%$ $LDT8291_{NOx} = 4.659 \times 10^{7}\ gm$

$LDV8291_{VOC} := V_{8291} \cdot (Total\_Worcester\_miles) \cdot LDV\_8291_{VOC} \cdot LDC\%$ $LDV8291_{VOC} = 1.242 \times 10^{8}\ gm$

$LDT8291_{VOC} := V_{8291} \cdot (Total\_Worcester\_miles) \cdot LDT\_8291_{VOC} \cdot LDT\%$ $LDT8291_{VOC} = 3.106 \times 10^{7}\ gm$

Pre 1982

$LDVP82_{CO} := V_{P82} \cdot (Total\_Worcester\_miles) \cdot LDV\_P82_{CO} \cdot LDC\%$ $LDVP82_{CO} = 5.04 \times 10^{8}\ gm$

$LDTP82_{CO} := V_{P82} \cdot (Total\_Worcester\_miles) \cdot LDT\_P82_{CO} \cdot LDT\%$ $LDTP82_{CO} = 1.275 \times 10^{8}\ gm$

$LDVP82_{NOx} := V_{P82} \cdot (Total\_Worcester\_miles) \cdot LDV\_P82_{NOx} \cdot LDC\%$ $LDVP82_{NOx} = 4.852 \times 10^{7}\ gm$

$LDTP82_{NOx} := V_{P82} \cdot (Total\_Worcester\_miles) \cdot LDT\_P82_{NOx} \cdot LDT\%$ $LDTP82_{NOx} = 1.434 \times 10^{7}\ gm$

$LDVP82_{VOC} := V_{P82} \cdot (Total\_Worcester\_miles) \cdot LDV\_P82_{VOC} \cdot LDC\%$ $LDVP82_{VOC} = 3.922 \times 10^{7}\ gm$

$LDTP82_{VOC} := V_{P82} \cdot (Total\_Worcester\_miles) \cdot LDT\_P82_{VOC} \cdot LDT\%$ $LDTP82_{VOC} = 1.157 \times 10^{7}\ gm$

Total Emissions of New Vehicles, (English Tons):

Carbon Monoxide:

$$CO_{new} := LMM_{CO} + SmC_{CO} + SUV_{CO}$$

$$CO_{new} = 704.5\,ton$$

$LMM_{CO} = 365.2\,ton$

$SmC_{CO} = 166.2\,ton$

$SUV_{CO} = 173.1\,ton$

Nitrous Oxides:

$$NOx_{new} := LMM_{NOx} + SmC_{NOx} + SUV_{NOx}$$

$$NOx_{new} = 57.2\,ton$$

$LMM_{NOx} = 26.5\,ton$

$SmC_{NOx} = 13.2\,ton$

$SUV_{NOx} = 17.5\,ton$

Hydocarbons:

$$HC_{new} := LMM_{HC} + SmC_{HC} + SUV_{HC}$$

$$HC_{new} = 24.9\,ton$$

$LMM_{HC} = 10.7\,ton$

$SmC_{HC} = 5.6\,ton$

$SUV_{HC} = 8.5\,ton$

Total Emissions:

$$Emissions_{new} := CO_{new} + NOx_{new} + HC_{new}$$

$$Emissions_{new} = 786.6\,ton$$

Total Emissions of Older Vehicles, (English Tons):

Carbon Monoxide:

$LDV9295_{CO} = 793.7\,ton$ $LDV8291_{CO} = 719\,ton$ $LDVP82_{CO} = 555.6\,ton$

$LDT9295_{CO} = 583.6\,ton$ $LDT8291_{CO} = 466\,ton$ $LDTP82_{CO} = 140.6\,ton$

$$CO_{old} := LDV9295_{CO} + LDT9295_{CO} + LDV8291_{CO} + LDT8291_{CO} \cdots + LDVP82_{CO} + LDTP82_{CO}$$

Nitrous Oxides:

$LDV9295_{NOx} = 233.4\,ton$ $LDV8291_{NOx} = 171.2\,ton$ $LDVP82_{NOx} = 53.5\,ton$

$LDT9295_{NOx} = 70\,ton$ $LDT8291_{NOx} = 51.4\,ton$ $LDTP82_{NOx} = 15.8\,ton$

$$NOx_{old} := LDV9295_{NOx} + LDT9295_{NOx} + LDV8291_{NOx} + LDT8291_{NOx} \cdots + LDVP82_{NOx} + LDTP82_{NOx}$$

HydroCarbons and Volatile Organic Compounds:

$LDV9295_{HC} = 95.7\,ton$ $LDV8291_{VOC} = 137\,ton$ $LDVP82_{VOC} = 43.2\,ton$

$LDT9295_{HC} = 39.1\,ton$ $LDT8291_{VOC} = 34.2\,ton$ $LDTP82_{VOC} = 12.7\,ton$

$$HC_{old} := LDV9295_{HC} + LDT9295_{HC} + LDV8291_{VOC} + LDT8291_{VOC} \cdots + LDVP82_{VOC} + LDTP82_{VOC}$$

Totals for Older Vehicles:

$CO_{old} = 3258.5\,ton$ $NOx_{old} = 595.3\,ton$ $HC_{old} = 362\,ton$

$Emissions_{old} := CO_{old} + NOx_{old} + HC_{old}$

$Emissions_{old} = 4215.8\,ton$

Calculate emissions of a population of SLEV

$Number\_of\_SLEV := (0.5)\cdot\left(V\%_{new}\right)\cdot Worcester\_population\cdot Vehicles\_per\_person$

$Commuter\_miles_{SLEV} := (Travel\_distance)\cdot\left(\frac{2}{day}\right)\cdot(Work\_days)\cdot(Number\_of\_SLEV)$

$Commuter\_miles_{SLEV} = 0.166\,billion\_miles$ driven per year

$Avg\_commuter\_miles_{SLEV} := \frac{Commuter\_miles_{SLE}}{Number\_of\_SLEV}$ $Avg\_commuter\_miles_{SLEV} = 3.654\times10^{3}\,mi$ per vehicle driven per year

$Weekend\_miles_{SLEV} := \left(\frac{Travel\_distance}{2}\right)\cdot\left(\frac{2}{day}\right)\cdot(Week\_ends)\cdot(Number\_of\_SLEV)$

$Weekend\_miles_{SLEV} = 32.985\,million\_miles$ driven per year

$Avg\_weekend\_miles_{SLEV} := \frac{Weekend\_miles_{SLEV}}{Number\_of\_SLEV}$ $Avg\_weekend\_miles_{SLEV} = 728\,mi$ per vehicle driven per year

$Total\_Worcester\_miles_{SLEV} := Weekend\_miles_{SLEV} + Commuter\_miles_{SLEV}$

$Total\_Worcester\_miles_{SLEV} = 0.199\,billion\_miles$ driven per year

$SLEV_{CO} := Total\_Worcester\_miles_{SLEV}\cdot SLEV\_CO$ $SLEV_{CO} = 218.855\,ton$

$SLEV_{HC} := Total\_Worcester\_miles_{SLEV}\cdot SLEV\_HC$ $SLEV_{HC} = 2.189\,ton$

$SLEV_{NOx} := Total\_Worcester\_miles_{SLEV}\cdot SLEV\_NOx$ $SLEV_{NOx} = 4.377\,ton$

$Total\_Emissions := Emissions_{new} + Emissions_{old} + SLEV_{CO} + SLEV_{HC} + SLEV_{NOx}$

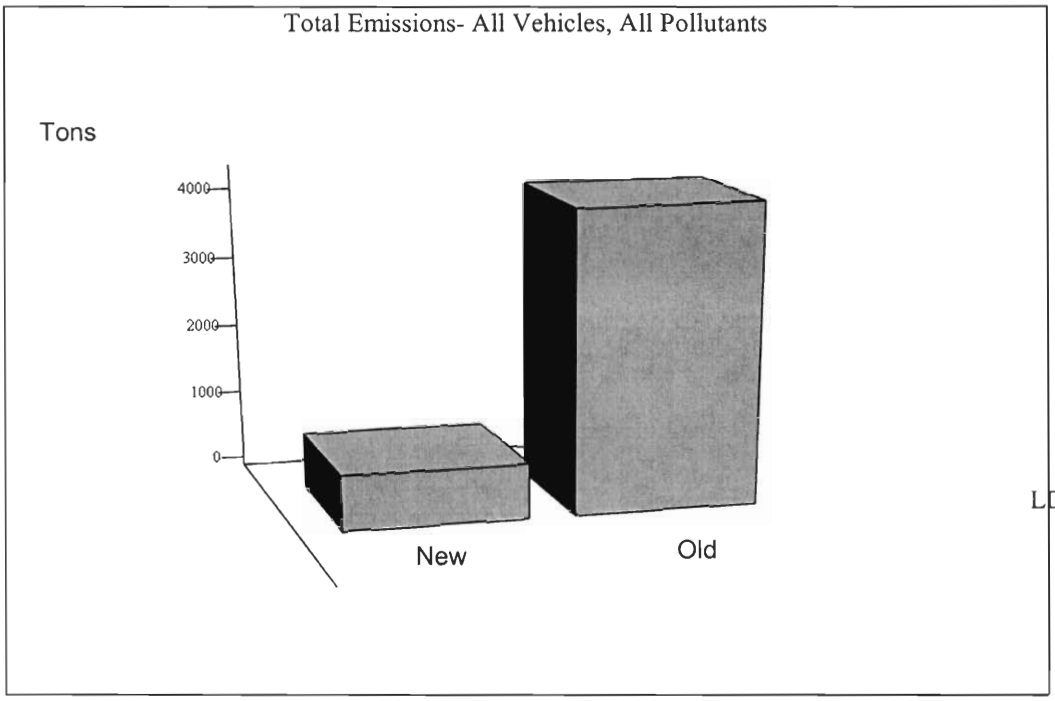
$Total\_Emissions = 5227.8\,ton$

$CO_{Tot} := SLEV_{CO} + CO_{old} + CO_{new}$ $CO_{Tot} = 4181.9\,ton$

$NOx_{Tot} := SLEV_{NOx} + NOx_{old} + NOx_{new}$ $NOx_{Tot} = 656.9\,ton$

$HC_{Tot} := SLEV_{HC} + HC_{old} + HC_{new}$ $HC_{Tot} = 389\,ton$

$$Graph1 := \left(\frac{Emissions_{new}}{2000} \quad \frac{Emissions_{old}}{2000} \right)$$



LDTI

Replacing 50% of all old Vehicles w/Hybrids

billion_miles := $10^9 \cdot mi$

million_miles := $10^6 \cdot mi$

Assumptions:

Vehicles traveling through Worcester Travel an average of 7 miles each

Travel_distance := $7 \cdot mi$

Work_days := $261 \cdot day$

Week_ends := $104 \cdot day$

City Data:

Worcester_population := 254900 people

Vehicles_per_person := 0.79

Percentages of Vehicle Types:

Newer Vehicles:

SUV := 0.275 SmC := 0.21 LMM := 0.51

Older Vehicles:

SUV_{old} := 0.20 SmC_{old} := 0.20 LMM_{old} := 0.60 LDT% := SUV_{old}

LDC% := $SmC_{old} + LMM_{old}$

Age distribution of Vehicles on the Roads:

1996 - 2002 V_{9602} := 0.45

1992 - 1995 $V_{9295} := 0.30 \cdot (0.50)$

1982 - 1991 $V_{8291} := 0.22(0.50)$

Pre 1982 $V_{P82} := 0.03 \cdot (0.50)$

$V\%_{old}$:= 0.55 55% of all worcester vehicles are "old"

Transitional Low Emissions Vehicle Data:

TLEV_NMOG := $0.125 \cdot \frac{gm}{mi}$ TLEV_NOx := $0.4 \cdot \frac{gm}{mi}$

TLEV_CO := $3.4 \cdot \frac{gm}{mi}$ TLEV_HCHO := $0.015 \cdot \frac{gm}{mi}$

TLEV HC := TLEV NMOG + TLEV_HCHO

TLEV_HC = $0.14 \frac{gm}{mi}$

Low Emissions Vehicle Data:

LEV_NMOG := $0.075 \cdot \frac{gm}{mi}$ LEV_NOx := $0.2 \cdot \frac{gm}{mi}$

LEV_CO := $3.4 \cdot \frac{gm}{mi}$ LEV_HCHO := $0.015 \cdot \frac{gm}{mi}$

LEV_HC := LEV_NMOG + LEV_HCHO

LEV_HC = $0.09 \frac{gm}{mi}$

Ultra Low Emissions Vehicle Data:

$$ULEV\_NMOG := 0.04 \cdot \frac{gm}{mi} \qquad ULEV\_NOx := 0.2 \cdot \frac{gm}{mi}$$

$$ULEV\_CO := 1.7 \cdot \frac{gm}{mi} \qquad ULEV\_HCHO := 0.008 \cdot \frac{gm}{mi}$$

$$ULEV\_HC := ULEV\_NMOG + ULEV\_HCHO$$

$$ULEV\_HC = 0.048 \frac{gm}{mi}$$

Super Low Emissions Vehicle Data:

$$SLEV\_CO := 1.0 \cdot \frac{gm}{mi} \qquad SLEV\_HC := 0.01 \cdot \frac{gm}{mi} \qquad SLEV\_NOx := 0.02 \cdot \frac{gm}{mi}$$

Zero Emissions Vehicle Data:

$$ZEV\_CO := 0 \cdot \frac{gm}{mi} \qquad ZEV\_HC := 0 \cdot \frac{gm}{mi} \qquad ZEV\_NOx := 0 \cdot \frac{gm}{mi}$$

Tier 1 Emissions Data:

$$T1\_CO := 4.2 \cdot \frac{gm}{mi} \qquad T1\_HC := 0.31 \cdot \frac{gm}{mi} \qquad T1\_NOx := 0.6 \cdot \frac{gm}{mi}$$

Tabulated Vehicle Distribution for New Vehicles:

$$SUV\_ZEV\_percentage := \frac{0.21}{100} \qquad LMM\_ZEV\_percentage := 0$$

$$SUV\_SLEV\_percentage := \frac{0}{100} \qquad LMM\_SLEV\_percentage := \frac{0}{100}$$

$$SUV\_ULEV\_percentage := \frac{4.5}{100} \qquad LMM\_ULEV\_percentage := \frac{19.13}{100}$$

$$SUV\_LEV\_percentage := \frac{51.82}{100} \qquad LMM\_LEV\_percentage := \frac{70.40}{100}$$

$$SUV\_TLEV\_percentage := \frac{1.5}{100} \qquad LMM\_TLEV\_percentage := \frac{7.94}{100}$$

$$SUV\_T1\_percentage := \frac{41.11}{100} \qquad LMM\_T1\_percentage := \frac{2.17}{100}$$

$$SmC\_ZEV\_percentage := \frac{0.26}{100} \qquad SmC\_LEV\_percentage := \frac{65.17}{100}$$

$$SmC\_SLEV\_percentage := \frac{0}{100} \qquad SmC\_TLEV\_percentage := \frac{9.5}{100}$$

$$SmC\_ULEV\_percentage := \frac{15.04}{100} \qquad SmC\_T1\_percentage := \frac{8.97}{100}$$

Ultra Low Emissions Vehicle Data:

$$ULEV\_NMOG := 0.04 \cdot \frac{gm}{mi} \qquad ULEV\_NOx := 0.2 \cdot \frac{gm}{mi}$$

$$ULEV\_CO := 1.7 \cdot \frac{gm}{mi} \qquad ULEV\_HCHO := 0.008 \cdot \frac{gm}{mi}$$

$$ULEV\_HC := ULEV\_NMOG + ULEV\_HCHO$$

$$ULEV\_HC = 0.048 \frac{gm}{mi}$$

Super Low Emissions Vehicle Data:

$$SLEV\_CO := 1.0 \cdot \frac{gm}{mi} \qquad SLEV\_HC := 0.01 \cdot \frac{gm}{mi} \qquad SLEV\_NOx := 0.02 \cdot \frac{gm}{mi}$$

Zero Emissions Vehicle Data:

$$ZEV\_CO := 0 \cdot \frac{gm}{mi} \qquad ZEV\_HC := 0 \cdot \frac{gm}{mi} \qquad ZEV\_NOx := 0 \cdot \frac{gm}{mi}$$

Tier 1 Emissions Data:

$$T1\_CO := 4.2 \cdot \frac{gm}{mi} \qquad T1\_HC := 0.31 \cdot \frac{gm}{mi} \qquad T1\_NOx := 0.6 \cdot \frac{gm}{mi}$$

Tabulated Vehicle Distribution for New Vehicles:

$$SUV\_ZEV\_percentage := \frac{0.21}{100} \qquad LMM\_ZEV\_percentage := 0$$

$$SUV\_SLEV\_percentage := \frac{0}{100} \qquad LMM\_SLEV\_percentage := \frac{0}{100}$$

$$SUV\_ULEV\_percentage := \frac{4.5}{100} \qquad LMM\_ULEV\_percentage := \frac{19.13}{100}$$

$$SUV\_LEV\_percentage := \frac{51.82}{100} \qquad LMM\_LEV\_percentage := \frac{70.40}{100}$$

$$SUV\_TLEV\_percentage := \frac{1.5}{100} \qquad LMM\_TLEV\_percentage := \frac{7.94}{100}$$

$$SUV\_T1\_percentage := \frac{41.11}{100} \qquad LMM\_T1\_percentage := \frac{2.17}{100}$$

$$SmC\_ZEV\_percentage := \frac{0.26}{100} \qquad SmC\_LEV\_percentage := \frac{65.17}{100}$$

$$SmC\_SLEV\_percentage := \frac{0}{100} \qquad SmC\_TLEV\_percentage := \frac{9.5}{100}$$

$$SmC\_ULEV\_percentage := \frac{15.04}{100} \qquad SmC\_T1\_percentage := \frac{8.97}{100}$$

$$SUV_{CO} := V_{9602} \cdot \begin{bmatrix} (Total\_Worcester\_miles) \cdot (SUV\_on\_road) \cdot (SUV\_ZEV\_percentage) \cdot (ZEV\_CO) \ldots \\ + (Total\_Worcester\_miles) \cdot (SUV\_on\_road) \cdot (SUV\_SLEV\_percentage) \cdot (SLEV\_CO) \ldots \\ + (Total\_Worcester\_miles) \cdot (SUV\_on\_road) \cdot (SUV\_T1\_percentage) \cdot (T1\_CO) \ldots \\ + (Total\_Worcester\_miles) \cdot (SUV\_on\_road) \cdot (SUV\_TLEV\_percentage) \cdot (TLEV\_CO) \ldots \\ + (Total\_Worcester\_miles) \cdot (SUV\_on\_road) \cdot (SUV\_LEV\_percentage) \cdot (LEV\_CO) \ldots \\ + (Total\_Worcester\_miles) \cdot (SUV\_on\_road) \cdot (SUV\_ULEV\_percentage) \cdot (ULEV\_CO) \end{bmatrix}$$

$$SUV_{CO} = 3.14 \times 10^{8}\ gm$$

Emissions Due to New Small Cars

$$SmC_{NOx} := V_{9602} \cdot \begin{bmatrix} (Total\_Worcester\_miles) \cdot (SmC\_on\_road) \cdot (SmC\_ZEV\_percentage) \cdot (ZEV\_NOx) \ldots \\ + (Total\_Worcester\_miles) \cdot (SmC\_on\_road) \cdot (SmC\_SLEV\_percentage) \cdot (SLEV\_NOx) \ldots \\ + (Total\_Worcester\_miles) \cdot (SmC\_on\_road) \cdot (SmC\_T1\_percentage) \cdot (T1\_NOx) \ldots \\ + (Total\_Worcester\_miles) \cdot (SmC\_on\_road) \cdot (SmC\_TLEV\_percentage) \cdot (TLEV\_NOx) \ldots \\ + (Total\_Worcester\_miles) \cdot (SmC\_on\_road) \cdot (SmC\_LEV\_percentage) \cdot (LEV\_NOx) \ldots \\ + (Total\_Worcester\_miles) \cdot (SmC\_on\_road) \cdot (SmC\_ULEV\_percentage) \cdot (ULEV\_NOx) \end{bmatrix}$$

$$SmC_{NOx} = 2.399 \times 10^{7}\ gm$$

$$SmC_{HC} := V_{9602} \cdot \begin{bmatrix} (Total\_Worcester\_miles) \cdot (SmC\_on\_road) \cdot (SmC\_ZEV\_percentage) \cdot (ZEV\_HC) \ldots \\ + (Total\_Worcester\_miles) \cdot (SmC\_on\_road) \cdot (SmC\_SLEV\_percentage) \cdot (SLEV\_HC) \ldots \\ + (Total\_Worcester\_miles) \cdot (SmC\_on\_road) \cdot (SmC\_T1\_percentage) \cdot (T1\_HC) \ldots \\ + (Total\_Worcester\_miles) \cdot (SmC\_on\_road) \cdot (SmC\_TLEV\_percentage) \cdot (TLEV\_HC) \ldots \\ + (Total\_Worcester\_miles) \cdot (SmC\_on\_road) \cdot (SmC\_LEV\_percentage) \cdot (LEV\_HC) \ldots \\ + (Total\_Worcester\_miles) \cdot (SmC\_on\_road) \cdot (SmC\_ULEV\_percentage) \cdot (ULEV\_HC) \end{bmatrix}$$

$$SmC_{HC} = 1.017 \times 10^{7}\ gm$$

$$SmC_{CO} := V_{9602} \cdot \begin{bmatrix} (Total\_Worcester\_miles) \cdot (SmC\_on\_road) \cdot (SmC\_ZEV\_percentage) \cdot (ZEV\_CO) \ldots \\ + (Total\_Worcester\_miles) \cdot (SmC\_on\_road) \cdot (SmC\_SLEV\_percentage) \cdot (SLEV\_CO) \ldots \\ + (Total\_Worcester\_miles) \cdot (SmC\_on\_road) \cdot (SmC\_T1\_percentage) \cdot (T1\_CO) \ldots \\ + (Total\_Worcester\_miles) \cdot (SmC\_on\_road) \cdot (SmC\_TLEV\_percentage) \cdot (TLEV\_CO) \ldots \\ + (Total\_Worcester\_miles) \cdot (SmC\_on\_road) \cdot (SmC\_LEV\_percentage) \cdot (LEV\_CO) \ldots \\ + (Total\_Worcester\_miles) \cdot (SmC\_on\_road) \cdot (SmC\_ULEV\_percentage) \cdot (ULEV\_CO) \end{bmatrix}$$

$$SmC_{CO} = 3.016 \times 10^{8}\ gm$$

Emissions Due to New Large-Medium cars and Minivans

$$LMM_{NOx} := V_{9602}\cdot\left[\begin{array}{l}(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_ZEV\_percentage)\cdot(ZEV\_NOx)\ ... \\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_SLEV\_percentage)\cdot(SLEV\_NOx)\ ... \\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_T1\_percentage)\cdot(T1\_NOx)\ ... \\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_TLEV\_percentage)\cdot(TLEV\_NOx)\ ... \\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_LEV\_percentage)\cdot(LEV\_NOx)\ ... \\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_ULEV\_percentage)\cdot(ULEV\_NOx)\end{array}\right]$$

$$LMM_{NOx} = 4.816 \times 10^{7}\ gm$$

$$LMM_{HC} := V_{9602}\cdot\left[\begin{array}{l}(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_ZEV\_percentage)\cdot(ZEV\_HC)\ ... \\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_SLEV\_percentage)\cdot(SLEV\_HC)\ ... \\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_T1\_percentage)\cdot(T1\_HC)\ ... \\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_TLEV\_percentage)\cdot(TLEV\_HC)\ ... \\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_LEV\_percentage)\cdot(LEV\_HC)\ ... \\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_ULEV\_percentage)\cdot(ULEV\_HC)\end{array}\right]$$

$$LMM_{HC} = 1.945 \times 10^{7}\ gm$$

$$LMM_{CO} := V_{9602}\cdot\left[\begin{array}{l}(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_ZEV\_percentage)\cdot(ZEV\_CO)\ ... \\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_SLEV\_percentage)\cdot(SLEV\_CO)\ ... \\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_T1\_percentage)\cdot(T1\_CO)\ ... \\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_TLEV\_percentage)\cdot(TLEV\_CO)\ ... \\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_LEV\_percentage)\cdot(LEV\_CO)\ ... \\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_ULEV\_percentage)\cdot(ULEV\_CO)\end{array}\right]$$

$$LMM_{CO} = 6.626 \times 10^{8}\ gm$$

Emissions Due to Vehicles manufactured 1995 or before:

Note: Prior to 1996 vehicles were generally classified as either Light Duty Vehicles (LDV) or Light Dut Trucks (LDT)

Recalculated Old Vehicle Distributions

$LDV_{old} := SmC_{old} + LMM_{old}$ $LDV_{old} = 0.8$

$LDT_{old} := SUV_{old}$ $LDT_{old} = 0.2$

x100 percent distribution

1992 to 1995 Emissions Data:

By 1992, all vehicles had to conform to the following Federal standard:

$LDV\_9295_{CO} := 3.4 \cdot \frac{gm}{mi}$ $LDV\_9295_{HC} := 0.41 \cdot \frac{gm}{mi}$ $LDV\_9295_{NOx} := 1.0 \cdot \frac{gm}{mi}$

$LDT\_9295_{CO} := 10 \cdot \frac{gm}{mi}$ $LDT\_9295_{HC} := 0.67 \cdot \frac{gm}{mi}$ $LDT\_9295_{NOx} := 1.2 \cdot \frac{gm}{mi}$

1982 - 1991 Emissions Data:

In this time frame, HC were not regulated. Instead Volatile Organic Compounds (VOC) were the standard, and will be considered nearly equivalent to HC's

Vehicles older than 1991 have reached their full usefull life of 10 yrs / 100,000 mi

$LDV\_8291_{CO} := 4.2 \cdot \frac{gm}{mi}$ $LDV\_8291_{VOC} := 0.80 \cdot \frac{gm}{mi}$ $LDV\_8291_{NOx} := 1.0 \frac{gm}{mi}$

$LDT\_8291_{CO} := \frac{10 \cdot 8 + 18}{9} \cdot \frac{gm}{mi}$ $LDT\_8291_{VOC} := 0.80 \cdot \frac{gm}{mi}$ $LDT\_8291_{NOx} := 1.2 \cdot \frac{gm}{mi}$

Pre 1982 Data:

$LDV\_P82_{CO} := \frac{23 \cdot 2 + 39 \cdot 3 + 15 \cdot 5}{10} \cdot \frac{gm}{mi}$ $LDV\_P82_{NOx} := \frac{3 \cdot 3 + 3.1 \cdot 2 + 2 \cdot 4 + 1 \cdot 2}{11} \cdot \frac{gm}{mi}$

$LDV\_P82_{VOC} := \frac{3.4 \cdot 3 + 1.5 \cdot 5 + 0.41 \cdot 2}{10} \cdot \frac{gm}{mi}$

$LDT\_P82_{CO} := \frac{39 \cdot 3 + 20 \cdot 5 + 18 \cdot 4}{12} \cdot \frac{gm}{mi}$ $LDT\_P82_{VOC} := \frac{3.4 \cdot 3 + 2 \cdot 4 + 1.7 \cdot 6}{13} \cdot \frac{gm}{mi}$

$LDT\_P82_{NOx} := \frac{3 \cdot 3 + 3.1 \cdot 4 + 2.3 \cdot 6}{13} \cdot \frac{gm}{mi}$

Emissions Calculations:

1992 - 1995

$LDV9295_{CO} := V_{9295} \cdot (Total\_Worcester\_miles) \cdot LDV\_9295_{CO} \cdot LDC\%$ $LDV9295_{CO} = 3.6 \times 10^{8}\ gm$

$LDT9295_{CO} := V_{9295} \cdot (Total\_Worcester\_miles) \cdot LDT\_9295_{CO} \cdot LDT\%$ $LDT9295_{CO} = 2.647 \times 10^{8}\ gm$

$LDV9295_{NOx} := V_{9295} \cdot (Total\_Worcester\_miles) \cdot LDV\_9295_{NOx} \cdot LDC\%$ $LDV9295_{NOx} = 1.059 \times 10^{8}\ gm$

$LDT9295_{NOx} := V_{9295} \cdot (Total\_Worcester\_miles) \cdot LDT\_9295_{NOx} \cdot LDT\%$ $LDT9295_{NOx} = 3.177 \times 10^{7}\ gm$

$LDV9295_{HC} := V_{9295} \cdot (Total\_Worcester\_miles) \cdot LDV\_9295_{HC} \cdot LDC\%$ $LDV9295_{HC} = 4.341 \times 10^{7}\ gm$

$LDT9295_{HC} := V_{9295} \cdot (Total\_Worcester\_miles) \cdot LDT\_9295_{HC} \cdot LDT\%$ $LDT9295_{HC} = 1.774 \times 10^{7}\ gm$

1982-1991

$LDV8291_{CO} := V_{8291} \cdot (Total\_Worcester\_miles) \cdot LDV\_8291_{CO} \cdot LDC\%$ $LDV8291_{CO} = 3.261 \times 10^{8}\ gm$

$LDT8291_{CO} := V_{8291} \cdot (Total\_Worcester\_miles) \cdot LDT\_8291_{CO} \cdot LDT\%$ $LDT8291_{CO} = 2.114 \times 10^{8}\ gm$

$LDV8291_{NOx} := V_{8291} \cdot (Total\_Worcester\_miles) \cdot LDV\_8291_{NOx} \cdot LDC\%$ $LDV8291_{NOx} = 7.765 \times 10^{7}\ gm$

$LDT8291_{NOx} := V_{8291} \cdot (Total\_Worcester\_miles) \cdot LDT\_8291_{NOx} \cdot LDT\%$ $LDT8291_{NOx} = 2.33 \times 10^{7}\ gm$

$LDV8291_{VOC} := V_{8291} \cdot (Total\_Worcester\_miles) \cdot LDV\_8291_{VOC} \cdot LDC\%$ $LDV8291_{VOC} = 6.212 \times 10^{7}\ gm$

$LDT8291_{VOC} := V_{8291} \cdot (Total\_Worcester\_miles) \cdot LDT\_8291_{VOC} \cdot LDT\%$ $LDT8291_{VOC} = 1.553 \times 10^{7}\ gm$

Pre 1982

$LDVP82_{CO} := V_{P82} \cdot (Total\_Worcester\_miles) \cdot LDV\_P82_{CO} \cdot LDC\%$ $LDVP82_{CO} = 2.52 \times 10^{8}\ gm$

$LDTP82_{CO} := V_{P82} \cdot (Total\_Worcester\_miles) \cdot LDT\_P82_{CO} \cdot LDT\%$ $LDTP82_{CO} = 6.375 \times 10^{7}\ gm$

$LDVP82_{NOx} := V_{P82} \cdot (Total\_Worcester\_miles) \cdot LDV\_P82_{NOx} \cdot LDC\%$ $LDVP82_{NOx} = 2.426 \times 10^{7}\ gm$

$LDTP82_{NOx} := V_{P82} \cdot (Total\_Worcester\_miles) \cdot LDT\_P82_{NOx} \cdot LDT\%$ $LDTP82_{NOx} = 7.168 \times 10^{6}\ gm$

$LDVP82_{VOC} := V_{P82} \cdot (Total\_Worcester\_miles) \cdot LDV\_P82_{VOC} \cdot LDC\%$ $LDVP82_{VOC} = 1.961 \times 10^{7}\ gm$

$LDTP82_{VOC} := V_{P82} \cdot (Total\_Worcester\_miles) \cdot LDT\_P82_{VOC} \cdot LDT\%$ $LDTP82_{VOC} = 5.783 \times 10^{6}\ gm$

Total Emissions of New Vehicles, (English Tons):

Carbon Monoxide:

$$CO_{new} := LMM_{CO} + SmC_{CO} + SUV_{CO}$$

$$CO_{new} = 1409\,ton$$

$LMM_{CO} = 730.4\,ton$

$SmC_{CO} = 332.4\,ton$

$SUV_{CO} = 346.1\,ton$

Nitrous Oxides:

$$NOx_{new} := LMM_{NOx} + SmC_{NOx} + SUV_{NOx}$$

$$NOx_{new} = 114.5\,ton$$

$LMM_{NOx} = 53.1\,ton$

$SmC_{NOx} = 26.4\,ton$

$SUV_{NOx} = 35\,ton$

Hydocarbons:

$$HC_{new} := LMM_{HC} + SmC_{HC} + SUV_{HC}$$

$$HC_{new} = 49.7\,ton$$

$LMM_{HC} = 21.4\,ton$

$SmC_{HC} = 11.2\,ton$

$SUV_{HC} = 17.1\,ton$

Total Emissions:

$$Emissions_{new} := CO_{new} + NOx_{new} + HC_{new}$$

$$Emissions_{new} = 1573.2\,ton$$

Total Emissions of Older Vehicles, (English Tons):

Carbon Monoxide:

$LDV9295_{CO} = 396.9\,ton$ $LDV8291_{CO} = 359.5\,ton$ $LDVP82_{CO} = 277.8\,ton$

$LDT9295_{CO} = 291.8\,ton$ $LDT8291_{CO} = 233\,ton$ $LDTP82_{CO} = 70.3\,ton$

$$CO_{old} := LDV9295_{CO} + LDT9295_{CO} + LDV8291_{CO} + LDT8291_{CO} \ldots + LDVP82_{CO} + LDTP82_{CO}$$

Nitrous Oxides:

$LDV9295_{NOx} = 116.7\,ton$ $LDV8291_{NOx} = 85.6\,ton$ $LDVP82_{NOx} = 26.7\,ton$

$LDT9295_{NOx} = 35\,ton$ $LDT8291_{NOx} = 25.7\,ton$ $LDTP82_{NOx} = 7.9\,ton$

$$NOx_{old} := LDV9295_{NOx} + LDT9295_{NOx} + LDV8291_{NOx} + LDT8291_{NOx} \ldots + LDVP82_{NOx} + LDTP82_{NOx}$$

HydroCarbons and Volatile Organic Compounds:

$LDV9295_{HC} = 47.9\,ton$ $LDV8291_{VOC} = 68.5\,ton$ $LDVP82_{VOC} = 21.6\,ton$

$LDT9295_{HC} = 19.6\,ton$ $LDT8291_{VOC} = 17.1\,ton$ $LDTP82_{VOC} = 6.4\,ton$

$$HC_{old} := LDV9295_{HC} + LDT9295_{HC} + LDV8291_{VOC} + LDT8291_{VOC} \ldots + LDVP82_{VOC} + LDTP82_{VOC}$$

Totals for Older Vehicles:

$CO_{old} = 1629.3\,ton$ $NOx_{old} = 297.7\,ton$ $HC_{old} = 181\,ton$

$Emissions_{old} := CO_{old} + NOx_{old} + HC_{old}$

$Emissions_{old} = 2107.9\,ton$

Calculate emissions of a population of SLEV

$Number\_of\_SLEV := (0.50)\cdot\left(V\%_{old}\right)\cdot Worcester\_population\cdot Vehicles\_per\_person$

$Commuter\_miles_{SLEV} := (Travel\_distance)\cdot\left(\frac{2}{day}\right)\cdot(Work\_days)\cdot(Number\_of\_SLEV)$

$Commuter\_miles_{SLEV} = 0.202\,billion\_miles$ driven per year

$Avg\_commuter\_miles_{SLEV} := \frac{Commuter\_miles_{SLE}}{Number\_of\_SLEV}$ $Avg\_commuter\_miles_{SLEV} = 3.654 \times 10^{3}\,mi$ per vehicle driven per year

$Weekend\_miles_{SLEV} := \left(\frac{Travel\_distance}{2}\right)\cdot\left(\frac{2}{day}\right)\cdot(Week\_ends)\cdot(Number\_of\_SLEV)$

$Weekend\_miles_{SLEV} = 40.314\,million\_miles$ driven per year

$Avg\_weekend\_miles_{SLEV} := \frac{Weekend\_miles_{SLEV}}{Number\_of\_SLEV}$ $Avg\_weekend\_miles_{SLEV} = 728\,mi$ per venicle driven per year

$Total\_Worcester\_miles_{SLEV} := Weekend\_miles_{SLEV} + Commuter\_miles_{SLEV}$

$Total\_Worcester\_miles_{SLEV} = 0.243\,billion\_miles$ driven per year

$SLEV_{CO} := Total\_Worcester\_miles_{SLEV}\cdot SLEV\_CO$ $SLEV_{CO} = 267.489\,ton$

$SLEV_{HC} := Total\_Worcester\_miles_{SLEV}\cdot SLEV\_HC$ $SLEV_{HC} = 2.675\,ton$

$SLEV_{NOx} := Total\_Worcester\_miles_{SLEV}\cdot SLEV\_NOx$ $SLEV_{NOx} = 5.35\,ton$

$Total\_Emissions := Emissions_{new} + Emissions_{old} + SLEV_{CO} + SLEV_{HC} + SLEV_{NOx}$

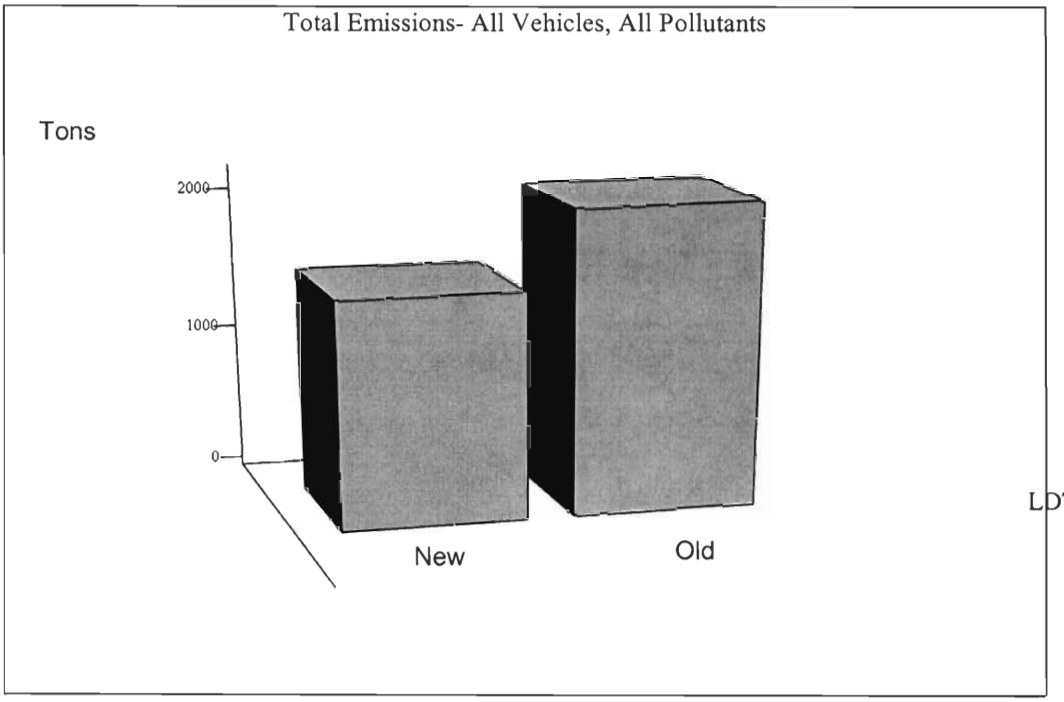
$Total\_Emissions = 3956.6\,ton$

$CO_{Tot} := SLEV_{CO} + CO_{old} + CO_{new}$ $CO_{Tot} = 3305.7\,ton$

$NOx_{Tot} := SLEV_{NOx} + NOx_{old} + NOx_{new}$ $NOx_{Tot} = 417.5\,ton$

$HC_{Tot} := SLEV_{HC} + HC_{old} + HC_{new}$ $HC_{Tot} = 233.4\,ton$

$$Graph1 := \left(\frac{Emissions_{new}}{2000} \quad \frac{Emissions_{old}}{2000} \right)$$



Replacing 75% of all new Vehicles w/Hybrids

billion_miles := $10^9 \cdot mi$

million_miles := $10^6 \cdot mi$

Assumptions:

Vehicles traveling through Worcester Travel an average of 7 miles each

Travel_distance := $7 \cdot mi$

Work_days := $261 \cdot day$

Week_ends := $104 \cdot day$

City Data:

Worcester_population := 254900 people

Vehicles_per_person := 0.79

Percentages of Vehicle Types:

Newer Vehicles:

SUV := 0.275 SmC := 0.21 LMM := 0.51

Older Vehicles:

SUV_{old} := 0.20 SmC_{old} := 0.20 LMM_{old} := 0.60 LDT% := SUV_{old}

LDC% := $SmC_{old} + LMM_{old}$

Age distribution of Vehicles on the Roads:

1996 - 2002 $V_{9602} := 0.45 \cdot (0.25)$

1992 - 1995 $V_{9295} := 0.30$

1982 - 1991 $V_{8291} := 0.22$

Pre 1982 $V_{P82} := 0.03$

$V\%_{new} := 0.45$

$V\%_{old} := 0.55$ 55% of all worcester vehicles are "old"

Transitional Low Emissions Vehicle Data:

TLEV_NMOG := $0.125 \cdot \frac{gm}{mi}$ TLEV_NOx := $0.4 \cdot \frac{gm}{mi}$

TLEV_CO := $3.4 \cdot \frac{gm}{mi}$ TLEV_HCHO := $0.015 \cdot \frac{gm}{mi}$

TLEV_HC := TLEV_NMOG + TLEV_HCHO

TLEV_HC = $0.14 \frac{gm}{mi}$

Low Emissions Vehicle Data:

LEV_NMOG := $0.075 \cdot \frac{gm}{mi}$ LEV_NOx := $0.2 \cdot \frac{gm}{mi}$

LEV_CO := $3.4 \cdot \frac{gm}{mi}$ LEV_HCHO := $0.015 \cdot \frac{gm}{mi}$

LEV_HC := LEV_NMOG + LEV_HCHO

LEV_HC = $0.09 \frac{gm}{mi}$

Ultra Low Emissions Vehicle Data:

$$ULEV\_NMOG := 0.04 \cdot \frac{gm}{mi} \qquad ULEV\_NOx := 0.2 \cdot \frac{gm}{mi}$$

$$ULEV\_CO := 1.7 \cdot \frac{gm}{mi} \qquad ULEV\_HCHO := 0.008 \cdot \frac{gm}{mi}$$

$$ULEV\_HC := ULEV\_NMOG + ULEV\_HCHO$$

$$ULEV\_HC = 0.048 \frac{gm}{mi}$$

Super Low Emissions Vehicle Data:

$$SLEV\_CO := 1.0 \cdot \frac{gm}{mi} \qquad SLEV\_HC := 0.01 \cdot \frac{gm}{mi} \qquad SLEV\_NOx := 0.02 \cdot \frac{gm}{mi}$$

Zero Emissions Vehicle Data:

$$ZEV\_CO := 0 \cdot \frac{gm}{mi} \qquad ZEV\_HC := 0 \cdot \frac{gm}{mi} \qquad ZEV\_NOx := 0 \cdot \frac{gm}{mi}$$

Tier 1 Emissions Data:

$$T1\_CO := 4.2 \cdot \frac{gm}{mi} \qquad T1\_HC := 0.31 \cdot \frac{gm}{mi} \qquad T1\_NOx := 0.6 \cdot \frac{gm}{mi}$$

Tabulated Vehicle Distribution for New Vehicles:

$$SUV\_ZEV\_percentage := \frac{0.21}{100} \qquad LMM\_ZEV\_percentage := 0$$

$$SUV\_SLEV\_percentage := \frac{0}{100} \qquad LMM\_SLEV\_percentage := \frac{0}{100}$$

$$SUV\_ULEV\_percentage := \frac{4.5}{100} \qquad LMM\_ULEV\_percentage := \frac{19.13}{100}$$

$$SUV\_LEV\_percentage := \frac{51.82}{100} \qquad LMM\_LEV\_percentage := \frac{70.40}{100}$$

$$SUV\_TLEV\_percentage := \frac{1.5}{100} \qquad LMM\_TLEV\_percentage := \frac{7.94}{100}$$

$$SUV\_T1\_percentage := \frac{41.11}{100} \qquad LMM\_T1\_percentage := \frac{2.17}{100}$$

$$SmC\_ZEV\_percentage := \frac{0.26}{100} \qquad SmC\_LEV\_percentage := \frac{65.17}{100}$$

$$SmC\_SLEV\_percentage := \frac{0}{100} \qquad SmC\_TLEV\_percentage := \frac{9.5}{100}$$

$$SmC\_ULEV\_percentage := \frac{15.04}{100} \qquad SmC\_T1\_percentage := \frac{8.97}{100}$$

Percentages of Each New Vehicle Type Observed on the Road:

SmC_on_road := .2395 LMM_on_road := .5418

SUV_on_road := .2187

Equations:

$$\text{Number\_of\_Vehicles} := 1.0 \cdot \text{Worcester\_population} \cdot \text{Vehicles\_per\_person}$$

$$\text{Number\_of\_Vehicles} = 201371$$

$$\text{Commuter\_miles} := (\text{Travel\_distance}) \cdot \left(\frac{2}{\text{day}}\right) \cdot (\text{Work\_days}) \cdot (\text{Number\_of\_Vehicles})$$

$$\text{Commuter\_miles} = 0.736\,\text{billion\_miles driven per year}$$

$$\text{Avg\_commuter\_miles} := \frac{\text{Commuter\_miles}}{\text{Number\_of\_Vehicles}} \qquad \text{Avg\_commuter\_miles} = 3.654 \times 10^3\ \text{mi per vehicle driven per year}$$

$$\text{Weekend\_miles} := \left(\frac{\text{Travel\_distance}}{2}\right) \cdot \left(\frac{2}{\text{day}}\right) \cdot (\text{Week\_ends}) \cdot (\text{Number\_of\_Vehicles})$$

$$\text{Weekend\_miles} = 146.598\,\text{million\_milesriven per year}$$

$$\text{Avg\_weekend\_miles} := \frac{\text{Weekend\_miles}}{\text{Number\_of\_Vehicles}} \qquad \text{Avg\_weekend\_miles} = 728\,\text{mi per vehicle driven per year}$$

$$\text{Total\_Worcester\_miles} := \text{Weekend\_miles} + \text{Commuter\_miles} \qquad \text{Total\_Worcester\_miles} = 0.882\,\text{billion\_miles driven per year}$$

Emissions Due to New SUV's

$$\text{SUV}_{\text{NOx}} := V_{9602} \cdot \left[\begin{array}{l} (\text{Total\_Worcester\_miles}) \cdot (\text{SUV\_on\_road}) \cdot (\text{SUV\_ZEV\_percentage}) \cdot (\text{ZEV\_NOx}) \ldots \\ +(\text{Total\_Worcester\_miles}) \cdot (\text{SUV\_on\_road}) \cdot (\text{SUV\_SLEV\_percentage}) \cdot (\text{SLEV\_NOx}) \ldots \\ +(\text{Total\_Worcester\_miles}) \cdot (\text{SUV\_on\_road}) \cdot (\text{SUV\_T1\_percentage}) \cdot (\text{T1\_NOx}) \ldots \\ +(\text{Total\_Worcester\_miles}) \cdot (\text{SUV\_on\_road}) \cdot (\text{SUV\_TLEV\_percentage}) \cdot (\text{TLEV\_NOx}) \ldots \\ +(\text{Total\_Worcester\_miles}) \cdot (\text{SUV\_on\_road}) \cdot (\text{SUV\_LEV\_percentage}) \cdot (\text{LEV\_NOx}) \ldots \\ +(\text{Total\_Worcester\_miles}) \cdot (\text{SUV\_on\_road}) \cdot (\text{SUV\_ULEV\_percentage}) \cdot (\text{ULEV\_NOx}) \end{array}\right]$$

$$\text{SUV}_{\text{NOx}} = 7.931 \times 10^6\,\text{gm}$$

$$\text{SUV}_{\text{HC}} := V_{9602} \cdot \left[\begin{array}{l} (\text{Total\_Worcester\_miles}) \cdot (\text{SUV\_on\_road}) \cdot (\text{SUV\_ZEV\_percentage}) \cdot (\text{ZEV\_HC}) \ldots \\ +(\text{Total\_Worcester\_miles}) \cdot (\text{SUV\_on\_road}) \cdot (\text{SUV\_SLEV\_percentage}) \cdot (\text{SLEV\_HC}) \ldots \\ +(\text{Total\_Worcester\_miles}) \cdot (\text{SUV\_on\_road}) \cdot (\text{SUV\_T1\_percentage}) \cdot (\text{T1\_HC}) \ldots \\ +(\text{Total\_Worcester\_miles}) \cdot (\text{SUV\_on\_road}) \cdot (\text{SUV\_TLEV\_percentage}) \cdot (\text{TLEV\_HC}) \ldots \\ +(\text{Total\_Worcester\_miles}) \cdot (\text{SUV\_on\_road}) \cdot (\text{SUV\_LEV\_percentage}) \cdot (\text{LEV\_HC}) \ldots \\ +(\text{Total\_Worcester\_miles}) \cdot (\text{SUV\_on\_road}) \cdot (\text{SUV\_ULEV\_percentage}) \cdot (\text{ULEV\_HC}) \end{array}\right]$$

$$\text{SUV}_{\text{HC}} = 3.872 \times 10^6\,\text{gm}$$

$$SUV_{CO} := V_{9602}\cdot\begin{bmatrix} (Total\_Worcester\_miles)\cdot(SUV\_on\_road)\cdot(SUV\_ZEV\_percentage)\cdot(ZEV\_CO) \ldots \\ +(Total\_Worcester\_miles)\cdot(SUV\_on\_road)\cdot(SUV\_SLEV\_percentage)\cdot(SLEV\_CO) \ldots \\ +(Total\_Worcester\_miles)\cdot(SUV\_on\_road)\cdot(SUV\_T1\_percentage)\cdot(T1\_CO) \ldots \\ +(Total\_Worcester\_miles)\cdot(SUV\_on\_road)\cdot(SUV\_TLEV\_percentage)\cdot(TLEV\_CO) \ldots \\ +(Total\_Worcester\_miles)\cdot(SUV\_on\_road)\cdot(SUV\_LEV\_percentage)\cdot(LEV\_CO) \ldots \\ +(Total\_Worcester\_miles)\cdot(SUV\_on\_road)\cdot(SUV\_ULEV\_percentage)\cdot(ULEV\_CO) \end{bmatrix}$$

$$SUV_{CO} = 7.851 \times 10^{7}\ gm$$

Emissions Due to New Small Cars

$$SmC_{NOx} := V_{9602}\cdot\begin{bmatrix} (Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_ZEV\_percentage)\cdot(ZEV\_NOx) \ldots \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_SLEV\_percentage)\cdot(SLEV\_NOx) \ldots \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_T1\_percentage)\cdot(T1\_NOx) \ldots \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_TLEV\_percentage)\cdot(TLEV\_NOx) \ldots \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_LEV\_percentage)\cdot(LEV\_NOx) \ldots \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_ULEV\_percentage)\cdot(ULEV\_NOx) \end{bmatrix}$$

$$SmC_{NOx} = 5.997 \times 10^{6}\ gm$$

$$SmC_{HC} := V_{9602}\cdot\begin{bmatrix} (Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_ZEV\_percentage)\cdot(ZEV\_HC) \ldots \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_SLEV\_percentage)\cdot(SLEV\_HC) \ldots \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_T1\_percentage)\cdot(T1\_HC) \ldots \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_TLEV\_percentage)\cdot(TLEV\_HC) \ldots \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_LEV\_percentage)\cdot(LEV\_HC) \ldots \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_ULEV\_percentage)\cdot(ULEV\_HC) \end{bmatrix}$$

$$SmC_{HC} = 2.543 \times 10^{6}\ gm$$

$$SmC_{CO} := V_{9602}\cdot\begin{bmatrix} (Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_ZEV\_percentage)\cdot(ZEV\_CO) \ldots \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_SLEV\_percentage)\cdot(SLEV\_CO) \ldots \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_T1\_percentage)\cdot(T1\_CO) \ldots \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_TLEV\_percentage)\cdot(TLEV\_CO) \ldots \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_LEV\_percentage)\cdot(LEV\_CO) \ldots \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_ULEV\_percentage)\cdot(ULEV\_CO) \end{bmatrix}$$

$$SmC_{CO} = 7.54 \times 10^{7}\ gm$$

Emissions Due to New Large-Medium cars and Minivans

$$LMM_{NOx} := V_{9602}\cdot\left[\begin{array}{l}(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_ZEV\_percentage)\cdot(ZEV\_NOx)\ ... \\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_SLEV\_percentage)\cdot(SLEV\_NOx)\ ... \\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_T1\_percentage)\cdot(T1\_NOx)\ ... \\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_TLEV\_percentage)\cdot(TLEV\_NOx)\ ... \\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_LEV\_percentage)\cdot(LEV\_NOx)\ ... \\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_ULEV\_percentage)\cdot(ULEV\_NOx)\end{array}\right]$$

$$LMM_{NOx} = 1.204 \times 10^{7}\,gm$$

$$LMM_{HC} := V_{9602}\cdot\left[\begin{array}{l}(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_ZEV\_percentage)\cdot(ZEV\_HC)\ ... \\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_SLEV\_percentage)\cdot(SLEV\_HC)\ ... \\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_T1\_percentage)\cdot(T1\_HC)\ ... \\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_TLEV\_percentage)\cdot(TLEV\_HC)\ ... \\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_LEV\_percentage)\cdot(LEV\_HC)\ ... \\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_ULEV\_percentage)\cdot(ULEV\_HC)\end{array}\right]$$

$$LMM_{HC} = 4.861 \times 10^{6}\,gm$$

$$LMM_{CO} := V_{9602}\cdot\left[\begin{array}{l}(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_ZEV\_percentage)\cdot(ZEV\_CO)\ ... \\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_SLEV\_percentage)\cdot(SLEV\_CO)\ ... \\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_T1\_percentage)\cdot(T1\_CO)\ ... \\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_TLEV\_percentage)\cdot(TLEV\_CO)\ ... \\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_LEV\_percentage)\cdot(LEV\_CO)\ ... \\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_ULEV\_percentage)\cdot(ULEV\_CO)\end{array}\right]$$

$$LMM_{CO} = 1.657 \times 10^{8}\,gm$$

Emissions Due to Vehicles manufactured 1995 or before:

Note: Prior to 1996 vehicles were generally classified as either Light Duty Vehicles (LDV) or Light Dut Trucks (LDT)

Recalculated Old Vehicle Distributions

$LDV_{old} := SmC_{old} + LMM_{old}$ $\quad LDV_{old} = 0.8$

$LDT_{old} := SUV_{old}$ $\quad LDT_{old} = 0.2$

x100 percent distribution

1992 to 1995 Emissions Data:

By 1992, all vehicles had to conform to the following Federal standard:

$LDV\_9295_{CO} := 3.4 \cdot \frac{gm}{mi}$ $\quad LDV\_9295_{HC} := 0.41 \cdot \frac{gm}{mi}$ $\quad LDV\_9295_{NOx} := 1.0 \cdot \frac{gm}{mi}$

$LDT\_9295_{CO} := 10 \cdot \frac{gm}{mi}$ $\quad LDT\_9295_{HC} := 0.67 \cdot \frac{gm}{mi}$ $\quad LDT\_9295_{NOx} := 1.2 \cdot \frac{gm}{mi}$

1982 - 1991 Emissions Data:

In this time frame, HC were not regulated. Instead Volatile Organic Compounds (VOC) were the standard, and will be considered nearly equivalent to HC's

Vehicles older than 1991 have reached their full usefull life of 10 yrs / 100,000 mi

$LDV\_8291_{CO} := 4.2 \cdot \frac{gm}{mi}$ $\quad LDV\_8291_{VOC} := 0.80 \cdot \frac{gm}{mi}$ $\quad LDV\_8291_{NOx} := 1.0 \frac{gm}{mi}$

$LDT\_8291_{CO} := \frac{10 \cdot 8 + 18}{9} \cdot \frac{gm}{mi}$ $\quad LDT\_8291_{VOC} := 0.80 \cdot \frac{gm}{mi}$ $\quad LDT\_8291_{NOx} := 1.2 \cdot \frac{gm}{mi}$

Pre 1982 Data:

$LDV\_P82_{CO} := \frac{23 \cdot 2 + 39 \cdot 3 + 15 \cdot 5}{10} \cdot \frac{gm}{mi}$ $\quad LDV\_P82_{NOx} := \frac{3 \cdot 3 + 3.1 \cdot 2 + 2 \cdot 4 + 1 \cdot 2}{11} \cdot \frac{gm}{mi}$

$LDV\_P82_{VOC} := \frac{3.4 \cdot 3 + 1.5 \cdot 5 + 0.41 \cdot 2}{10} \cdot \frac{gm}{mi}$

$LDT\_P82_{CO} := \frac{39 \cdot 3 + 20 \cdot 5 + 18 \cdot 4}{12} \cdot \frac{gm}{mi}$ $\quad LDT\_P82_{VOC} := \frac{3.4 \cdot 3 + 2 \cdot 4 + 1.7 \cdot 6}{13} \cdot \frac{gm}{mi}$

$LDT\_P82_{NOx} := \frac{3 \cdot 3 + 3.1 \cdot 4 + 2.3 \cdot 6}{13} \cdot \frac{gm}{mi}$

Emissions Calculations:

1992 - 1995

$LDV9295_{CO} := V_{9295} \cdot (Total\_Worcester\_miles) \cdot LDV\_9295_{CO} \cdot LDC\%$ $LDV9295_{CO} = 7.2 \times 10^{8}\ gm$

$LDT9295_{CO} := V_{9295} \cdot (Total\_Worcester\_miles) \cdot LDT\_9295_{CO} \cdot LDT\%$ $LDT9295_{CO} = 5.294 \times 10^{8}\ gm$

$LDV9295_{NOx} := V_{9295} \cdot (Total\_Worcester\_miles) \cdot LDV\_9295_{NOx} \cdot LDC\%$ $LDV9295_{NOx} = 2.118 \times 10^{8}\ gm$

$LDT9295_{NOx} := V_{9295} \cdot (Total\_Worcester\_miles) \cdot LDT\_9295_{NOx} \cdot LDT\%$ $LDT9295_{NOx} = 6.353 \times 10^{7}\ gm$

$LDV9295_{HC} := V_{9295} \cdot (Total\_Worcester\_miles) \cdot LDV\_9295_{HC} \cdot LDC\%$ $LDV9295_{HC} = 8.683 \times 10^{7}\ gm$

$LDT9295_{HC} := V_{9295} \cdot (Total\_Worcester\_miles) \cdot LDT\_9295_{HC} \cdot LDT\%$ $LDT9295_{HC} = 3.547 \times 10^{7}\ gm$

1982-1991

$LDV8291_{CO} := V_{8291} \cdot (Total\_Worcester\_miles) \cdot LDV\_8291_{CO} \cdot LDC\%$ $LDV8291_{CO} = 6.523 \times 10^{8}\ gm$

$LDT8291_{CO} := V_{8291} \cdot (Total\_Worcester\_miles) \cdot LDT\_8291_{CO} \cdot LDT\%$ $LDT8291_{CO} = 4.228 \times 10^{8}\ gm$

$LDV8291_{NOx} := V_{8291} \cdot (Total\_Worcester\_miles) \cdot LDV\_8291_{NOx} \cdot LDC\%$ $LDV8291_{NOx} = 1.553 \times 10^{8}\ gm$

$LDT8291_{NOx} := V_{8291} \cdot (Total\_Worcester\_miles) \cdot LDT\_8291_{NOx} \cdot LDT\%$ $LDT8291_{NOx} = 4.659 \times 10^{7}\ gm$

$LDV8291_{VOC} := V_{8291} \cdot (Total\_Worcester\_miles) \cdot LDV\_8291_{VOC} \cdot LDC\%$ $LDV8291_{VOC} = 1.242 \times 10^{8}\ gm$

$LDT8291_{VOC} := V_{8291} \cdot (Total\_Worcester\_miles) \cdot LDT\_8291_{VOC} \cdot LDT\%$ $LDT8291_{VOC} = 3.106 \times 10^{7}\ gm$

Pre 1982

$LDVP82_{CO} := V_{P82} \cdot (Total\_Worcester\_miles) \cdot LDV\_P82_{CO} \cdot LDC\%$ $LDVP82_{CO} = 5.04 \times 10^{8}\ gm$

$LDTP82_{CO} := V_{P82} \cdot (Total\_Worcester\_miles) \cdot LDT\_P82_{CO} \cdot LDT\%$ $LDTP82_{CO} = 1.275 \times 10^{8}\ gm$

$LDVP82_{NOx} := V_{P82} \cdot (Total\_Worcester\_miles) \cdot LDV\_P82_{NOx} \cdot LDC\%$ $LDVP82_{NOx} = 4.852 \times 10^{7}\ gm$

$LDTP82_{NOx} := V_{P82} \cdot (Total\_Worcester\_miles) \cdot LDT\_P82_{NOx} \cdot LDT\%$ $LDTP82_{NOx} = 1.434 \times 10^{7}\ gm$

$LDVP82_{VOC} := V_{P82} \cdot (Total\_Worcester\_miles) \cdot LDV\_P82_{VOC} \cdot LDC\%$ $LDVP82_{VOC} = 3.922 \times 10^{7}\ gm$

$LDTP82_{VOC} := V_{P82} \cdot (Total\_Worcester\_miles) \cdot LDT\_P82_{VOC} \cdot LDT\%$ $LDTP82_{VOC} = 1.157 \times 10^{7}\ gm$

Total Emissions of New Vehicles, (English Tons):

Carbon Monoxide:

$$CO_{new} := LMM_{CO} + SmC_{CO} + SUV_{CO}$$

$$CO_{new} = 352.2\,ton$$

$LMM_{CO} = 182.6\,ton$

$SmC_{CO} = 83.1\,ton$

$SUV_{CO} = 86.5\,ton$

Nitrous Oxides:

$$NOx_{new} := LMM_{NOx} + SmC_{NOx} + SUV_{NOx}$$

$$NOx_{new} = 28.6\,ton$$

$LMM_{NOx} = 13.3\,ton$

$SmC_{NOx} = 6.6\,ton$

$SUV_{NOx} = 8.7\,ton$

Hydocarbons:

$$HC_{new} := LMM_{HC} + SmC_{HC} + SUV_{HC}$$

$$HC_{new} = 12.4\,ton$$

$LMM_{HC} = 5.4\,ton$

$SmC_{HC} = 2.8\,ton$

$SUV_{HC} = 4.3\,ton$

Total Emissions:

$$Emissions_{new} := CO_{new} + NOx_{new} + HC_{new}$$

$$Emissions_{new} = 393.3\,ton$$

Total Emissions of Older Vehicles, (English Tons):

Carbon Monoxide:

$LDV9295_{CO} = 793.7\,ton$ $LDV8291_{CO} = 719\,ton$ $LDVP82_{CO} = 555.6\,ton$

$LDT9295_{CO} = 583.6\,ton$ $LDT8291_{CO} = 466\,ton$ $LDTP82_{CO} = 140.6\,ton$

$$CO_{old} := LDV9295_{CO} + LDT9295_{CO} + LDV8291_{CO} + LDT8291_{CO} \ldots + LDVP82_{CO} + LDTP82_{CO}$$

Nitrous Oxides:

$LDV9295_{NOx} = 233.4\,ton$ $LDV8291_{NOx} = 171.2\,ton$ $LDVP82_{NOx} = 53.5\,ton$

$LDT9295_{NOx} = 70\,ton$ $LDT8291_{NOx} = 51.4\,ton$ $LDTP82_{NOx} = 15.8\,ton$

$$NOx_{old} := LDV9295_{NOx} + LDT9295_{NOx} + LDV8291_{NOx} + LDT8291_{NOx} \ldots + LDVP82_{NOx} + LDTP82_{NOx}$$

HydroCarbons and Volatile Organic Compounds:

$LDV9295_{HC} = 95.7\,ton$ $LDV8291_{VOC} = 137\,ton$ $LDVP82_{VOC} = 43.2\,ton$

$LDT9295_{HC} = 39.1\,ton$ $LDT8291_{VOC} = 34.2\,ton$ $LDTP82_{VOC} = 12.7\,ton$

$$HC_{old} := LDV9295_{HC} + LDT9295_{HC} + LDV8291_{VOC} + LDT8291_{VOC} \ldots + LDVP82_{VOC} + LDTP82_{VOC}$$

Totals for Older Vehicles:

$CO_{old} = 3258.5\,ton$ $NOx_{old} = 595.3\,ton$ $HC_{old} = 362\,ton$

$Emissions_{old} := CO_{old} + NOx_{old} + HC_{old}$

$Emissions_{old} = 4215.8\,ton$

Calculate emissions of a population of SLEV

$Number\_of\_SLEV := (0.75)\cdot\left(V\%_{new}\right)\cdot Worcester\_population\cdot Vehicles\_per\_person$

$Commuter\_miles_{SLEV} := (Travel\_distance)\cdot\left(\frac{2}{day}\right)\cdot(Work\_days)\cdot(Number\_of\_SLEV)$

$Commuter\_miles_{SLEV} = 0.248\,billion\_miles$ driven per year

$Avg\_commuter\_miles_{SLEV} := \frac{Commuter\_miles_{SLE}}{Number\_of\_SLEV}$ $Avg\_commuter\_miles_{SLEV} = 3.654 \times 10^{3}\,mi$ per vehicle driven per year

$Weekend\_miles_{SLEV} := \left(\frac{Travel\_distance}{2}\right)\cdot\left(\frac{2}{day}\right)\cdot(Week\_ends)\cdot(Number\_of\_SLEV)$

$Weekend\_miles_{SLEV} = 49.477\,million\_miles$ driven per year

$Avg\_weekend\_miles_{SLEV} := \frac{Weekend\_miles_{SLEV}}{Number\_of\_SLEV}$ $Avg\_weekend\_miles_{SLEV} = 728\,mi$ per venicle driven per year

$Total\_Worcester\_miles_{SLEV} := Weekend\_miles_{SLEV} + Commuter\_miles_{SLEV}$

$Total\_Worcester\_miles_{SLEV} = 0.298\,billion\_miles$ driven per year

$SLEV_{CO} := Total\_Worcester\_miles_{SLEV}\cdot SLEV\_CO$ $SLEV_{CO} = 328.282\,ton$

$SLEV_{HC} := Total\_Worcester\_miles_{SLEV}\cdot SLEV\_HC$ $SLEV_{HC} = 3.283\,ton$

$SLEV_{NOx} := Total\_Worcester\_miles_{SLEV}\cdot SLEV\_NOx$ $SLEV_{NOx} = 6.566\,ton$

$Total\_Emissions := Emissions_{new} + Emissions_{old} + SLEV_{CO} + SLEV_{HC} + SLEV_{NOx}$

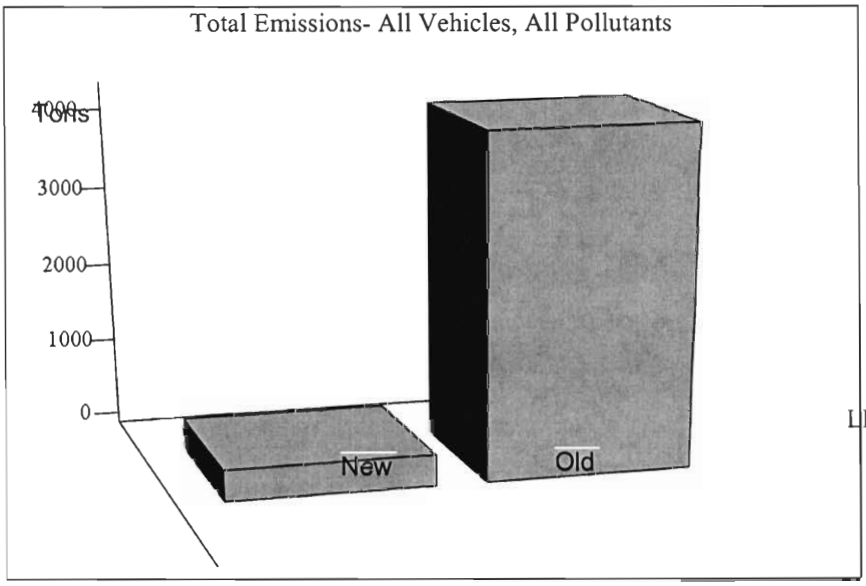
$Total\_Emissions = 4947.3\,ton$

$CO_{Tot} := SLEV_{CO} + CO_{old} + CO_{new}$ $CO_{Tot} = 3939\,ton$

$NOx_{Tot} := SLEV_{NOx} + NOx_{old} + NOx_{new}$ $NOx_{Tot} = 630.5\,ton$

$HC_{Tot} := SLEV_{HC} + HC_{old} + HC_{new}$ $HC_{Tot} = 377.7\,ton$

$$Graph1 := \left(\frac{Emissions_{new}}{2000} \quad \frac{Emissions_{old}}{2000} \right)$$



$LDTP82_{VOC} = 12.7\,t$

Replacing 75% of all old Vehicles w/Hybrids

billion_miles := $10^9 \cdot mi$

million_miles := $10^6 \cdot mi$

Assumptions:

Vehicles traveling through Worcester Travel an average of 7 miles each

Travel_distance := $7 \cdot mi$

Work_days := $261 \cdot day$

Week_ends := $104 \cdot day$

City Data:

Worcester_population := 254900 people

Vehicles_per_person := 0.79

Percentages of Vehicle Types:

Newer Vehicles:

SUV := 0.275 SmC := 0.21 LMM := 0.51

Older Vehicles:

SUV_{old} := 0.20 SmC_{old} := 0.20 LMM_{old} := 0.60 LDT% := SUV_{old}

LDC% := $SmC_{old} + LMM_{old}$

Age distribution of Vehicles on the Roads:

1996 - 2002 $V_{9602} := 0.45$

1992 - 1995 $V_{9295} := 0.30 \cdot (0.25)$

1982 - 1991 $V_{8291} := 0.22(0.25)$

Pre 1982 $V_{P82} := 0.03 \cdot (0.25)$

$V\%_{old} := 0.55$ 55% of all worcester vehicles are "old"

Transitional Low Emissions Vehicle Data:

TLEV_NMOG := $0.125 \cdot \frac{gm}{mi}$ TLEV_NOx := $0.4 \cdot \frac{gm}{mi}$

TLEV_CO := $3.4 \cdot \frac{gm}{mi}$ TLEV_HCHO := $0.015 \cdot \frac{gm}{mi}$

TLEV HC := TLEV NMOG + TLEV_HCHO

TLEV_HC = $0.14 \frac{gm}{mi}$

Low Emissions Vehicle Data:

LEV_NMOG := $0.075 \cdot \frac{gm}{mi}$ LEV_NOx := $0.2 \cdot \frac{gm}{mi}$

LEV_CO := $3.4 \cdot \frac{gm}{mi}$ LEV_HCHO := $0.015 \cdot \frac{gm}{mi}$

LEV_HC := LEV_NMOG + LEV_HCHO

LEV_HC = $0.09 \frac{gm}{mi}$

Ultra Low Emissions Vehicle Data:

$$ULEV\_NMOG := 0.04 \cdot \frac{gm}{mi} \qquad ULEV\_NOx := 0.2 \cdot \frac{gm}{mi}$$

$$ULEV\_CO := 1.7 \cdot \frac{gm}{mi} \qquad ULEV\_HCHO := 0.008 \cdot \frac{gm}{mi}$$

$$ULEV\_HC := ULEV\_NMOG + ULEV\_HCHO$$

$$ULEV\_HC = 0.048 \frac{gm}{mi}$$

Super Low Emissions Vehicle Data:

$$SLEV\_CO := 1.0 \cdot \frac{gm}{mi} \qquad SLEV\_HC := 0.01 \cdot \frac{gm}{mi} \qquad SLEV\_NOx := 0.02 \cdot \frac{gm}{mi}$$

Zero Emissions Vehicle Data:

$$ZEV\_CO := 0 \cdot \frac{gm}{mi} \qquad ZEV\_HC := 0 \cdot \frac{gm}{mi} \qquad ZEV\_NOx := 0 \cdot \frac{gm}{mi}$$

Tier 1 Emissions Data:

$$T1\_CO := 4.2 \cdot \frac{gm}{mi} \qquad T1\_HC := 0.31 \cdot \frac{gm}{mi} \qquad T1\_NOx := 0.6 \cdot \frac{gm}{mi}$$

Tabulated Vehicle Distribution for New Vehicles:

$$SUV\_ZEV\_percentage := \frac{0.21}{100} \qquad LMM\_ZEV\_percentage := 0$$

$$SUV\_SLEV\_percentage := \frac{0}{100} \qquad LMM\_SLEV\_percentage := \frac{0}{100}$$

$$SUV\_ULEV\_percentage := \frac{4.5}{100} \qquad LMM\_ULEV\_percentage := \frac{19.13}{100}$$

$$SUV\_LEV\_percentage := \frac{51.82}{100} \qquad LMM\_LEV\_percentage := \frac{70.40}{100}$$

$$SUV\_TLEV\_percentage := \frac{1.5}{100} \qquad LMM\_TLEV\_percentage := \frac{7.94}{100}$$

$$SUV\_T1\_percentage := \frac{41.11}{100} \qquad LMM\_T1\_percentage := \frac{2.17}{100}$$

$$SmC\_ZEV\_percentage := \frac{0.26}{100} \qquad SmC\_LEV\_percentage := \frac{65.17}{100}$$

$$SmC\_SLEV\_percentage := \frac{0}{100} \qquad SmC\_TLEV\_percentage := \frac{9.5}{100}$$

$$SmC\_ULEV\_percentage := \frac{15.04}{100} \qquad SmC\_T1\_percentage := \frac{8.97}{100}$$

Percentages of Each New Vehicle Type Observed on the Road:

SmC_on_road := .2395 LMM_on_road := .5418

SUV_on_road := .2187

Equations:

Number_of_Vehicles := 1.0·Worcester_population·Vehicles_per_person

Number_of_Vehicles = 201371

$$\text{Commuter\_miles} := (\text{Travel\_distance})\cdot\left(\frac{2}{\text{day}}\right)\cdot(\text{Work\_days})\cdot(\text{Number\_of\_Vehicles})$$

Commuter_miles = 0.736 billion_miles driven per year

$$\text{Avg\_commuter\_miles} := \frac{\text{Commuter\_miles}}{\text{Number\_of\_Vehicles}} \qquad \text{Avg\_commuter\_miles} = 3.654\times10^{3}\ \frac{\text{mi}}{\text{per vehicle driven per year}}$$

$$\text{Weekend\_miles} := \left(\frac{\text{Travel\_distance}}{2}\right)\cdot\left(\frac{2}{\text{day}}\right)\cdot(\text{Week\_ends})\cdot(\text{Number\_of\_Vehicles})$$

Weekend_miles = 146.598 millionmilesriven per year

$$\text{Avg\_weekend\_miles} := \frac{\text{Weekend\_miles}}{\text{Number\_of\_Vehicles}} \qquad \text{Avg\_weekend\_miles} = 728\ \frac{\text{mi}}{\text{per vehicle driven per year}}$$

Total_Worcester_miles := Weekend_miles + Commuter_miles Total_Worcester_miles = 0.882 billion_miles driven per year

Emissions Due to New SUV's

$$\text{SUV}_{\text{NOx}} := V_{9602}\cdot\left[\begin{array}{l}(\text{Total\_Worcester\_miles})\cdot(\text{SUV\_on\_road})\cdot(\text{SUV\_ZEV\_percentage})\cdot(\text{ZEV\_NOx})\ \ldots\\ +(\text{Total\_Worcester\_miles})\cdot(\text{SUV\_on\_road})\cdot(\text{SUV\_SLEV\_percentage})\cdot(\text{SLEV\_NOx})\ \ldots\\ +(\text{Total\_Worcester\_miles})\cdot(\text{SUV\_on\_road})\cdot(\text{SUV\_T1\_percentage})\cdot(\text{T1\_NOx})\ \ldots\\ +(\text{Total\_Worcester\_miles})\cdot(\text{SUV\_on\_road})\cdot(\text{SUV\_TLEV\_percentage})\cdot(\text{TLEV\_NOx})\ \ldots\\ +(\text{Total\_Worcester\_miles})\cdot(\text{SUV\_on\_road})\cdot(\text{SUV\_LEV\_percentage})\cdot(\text{LEV\_NOx})\ \ldots\\ +(\text{Total\_Worcester\_miles})\cdot(\text{SUV\_on\_road})\cdot(\text{SUV\_ULEV\_percentage})\cdot(\text{ULEV\_NOx})\end{array}\right]$$

$$\text{SUV}_{\text{NOx}} = 3.172\times10^{7}\ \text{gm}$$

$$\text{SUV}_{\text{HC}} := V_{9602}\cdot\left[\begin{array}{l}(\text{Total\_Worcester\_miles})\cdot(\text{SUV\_on\_road})\cdot(\text{SUV\_ZEV\_percentage})\cdot(\text{ZEV\_HC})\ \ldots\\ +(\text{Total\_Worcester\_miles})\cdot(\text{SUV\_on\_road})\cdot(\text{SUV\_SLEV\_percentage})\cdot(\text{SLEV\_HC})\ \ldots\\ +(\text{Total\_Worcester\_miles})\cdot(\text{SUV\_on\_road})\cdot(\text{SUV\_T1\_percentage})\cdot(\text{T1\_HC})\ \ldots\\ +(\text{Total\_Worcester\_miles})\cdot(\text{SUV\_on\_road})\cdot(\text{SUV\_TLEV\_percentage})\cdot(\text{TLEV\_HC})\ \ldots\\ +(\text{Total\_Worcester\_miles})\cdot(\text{SUV\_on\_road})\cdot(\text{SUV\_LEV\_percentage})\cdot(\text{LEV\_HC})\ \ldots\\ +(\text{Total\_Worcester\_miles})\cdot(\text{SUV\_on\_road})\cdot(\text{SUV\_ULEV\_percentage})\cdot(\text{ULEV\_HC})\end{array}\right]$$

$$\text{SUV}_{\text{HC}} = 1.549\times10^{7}\ \text{gm}$$

$$SUV_{CO} := V_{9602}\cdot\begin{bmatrix} (Total\_Worcester\_miles)\cdot(SUV\_on\_road)\cdot(SUV\_ZEV\_percentage)\cdot(ZEV\_CO) \dots \\ +(Total\_Worcester\_miles)\cdot(SUV\_on\_road)\cdot(SUV\_SLEV\_percentage)\cdot(SLEV\_CO) \dots \\ +(Total\_Worcester\_miles)\cdot(SUV\_on\_road)\cdot(SUV\_T1\_percentage)\cdot(T1\_CO) \dots \\ +(Total\_Worcester\_miles)\cdot(SUV\_on\_road)\cdot(SUV\_TLEV\_percentage)\cdot(TLEV\_CO) \dots \\ +(Total\_Worcester\_miles)\cdot(SUV\_on\_road)\cdot(SUV\_LEV\_percentage)\cdot(LEV\_CO) \dots \\ +(Total\_Worcester\_miles)\cdot(SUV\_on\_road)\cdot(SUV\_ULEV\_percentage)\cdot(ULEV\_CO) \end{bmatrix}$$

$$SUV_{CO} = 3.14 \times 10^{8}\,gm$$

Emissions Due to New Small Cars

$$SmC_{NOx} := V_{9602}\cdot\begin{bmatrix} (Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_ZEV\_percentage)\cdot(ZEV\_NOx) \dots \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_SLEV\_percentage)\cdot(SLEV\_NOx) \dots \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_T1\_percentage)\cdot(T1\_NOx) \dots \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_TLEV\_percentage)\cdot(TLEV\_NOx) \dots \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_LEV\_percentage)\cdot(LEV\_NOx) \dots \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_ULEV\_percentage)\cdot(ULEV\_NOx) \end{bmatrix}$$

$$SmC_{NOx} = 2.399 \times 10^{7}\,gm$$

$$SmC_{HC} := V_{9602}\cdot\begin{bmatrix} (Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_ZEV\_percentage)\cdot(ZEV\_HC) \dots \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_SLEV\_percentage)\cdot(SLEV\_HC) \dots \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_T1\_percentage)\cdot(T1\_HC) \dots \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_TLEV\_percentage)\cdot(TLEV\_HC) \dots \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_LEV\_percentage)\cdot(LEV\_HC) \dots \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_ULEV\_percentage)\cdot(ULEV\_HC) \end{bmatrix}$$

$$SmC_{HC} = 1.017 \times 10^{7}\,gm$$

$$SmC_{CO} := V_{9602}\cdot\begin{bmatrix} (Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_ZEV\_percentage)\cdot(ZEV\_CO) \dots \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_SLEV\_percentage)\cdot(SLEV\_CO) \dots \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_T1\_percentage)\cdot(T1\_CO) \dots \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_TLEV\_percentage)\cdot(TLEV\_CO) \dots \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_LEV\_percentage)\cdot(LEV\_CO) \dots \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_ULEV\_percentage)\cdot(ULEV\_CO) \end{bmatrix}$$

$$SmC_{CO} = 3.016 \times 10^{8}\,gm$$

Emissions Due to New Large-Medium cars and Minivans

$$LMM_{NOx} := V_{9602}\cdot\left[\begin{array}{l}(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_ZEV\_percentage)\cdot(ZEV\_NOx)\ ...\\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_SLEV\_percentage)\cdot(SLEV\_NOx)\ ...\\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_T1\_percentage)\cdot(T1\_NOx)\ ...\\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_TLEV\_percentage)\cdot(TLEV\_NOx)\ ...\\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_LEV\_percentage)\cdot(LEV\_NOx)\ ...\\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_ULEV\_percentage)\cdot(ULEV\_NOx)\end{array}\right]$$

$$LMM_{NOx} = 4.816\times 10^{7}\ gm$$

$$LMM_{HC} := V_{9602}\cdot\left[\begin{array}{l}(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_ZEV\_percentage)\cdot(ZEV\_HC)\ ...\\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_SLEV\_percentage)\cdot(SLEV\_HC)\ ...\\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_T1\_percentage)\cdot(T1\_HC)\ ...\\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_TLEV\_percentage)\cdot(TLEV\_HC)\ ...\\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_LEV\_percentage)\cdot(LEV\_HC)\ ...\\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_ULEV\_percentage)\cdot(ULEV\_HC)\end{array}\right]$$

$$LMM_{HC} = 1.945\times 10^{7}\ gm$$

$$LMM_{CO} := V_{9602}\cdot\left[\begin{array}{l}(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_ZEV\_percentage)\cdot(ZEV\_CO)\ ...\\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_SLEV\_percentage)\cdot(SLEV\_CO)\ ...\\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_T1\_percentage)\cdot(T1\_CO)\ ...\\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_TLEV\_percentage)\cdot(TLEV\_CO)\ ...\\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_LEV\_percentage)\cdot(LEV\_CO)\ ...\\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_ULEV\_percentage)\cdot(ULEV\_CO)\end{array}\right]$$

$$LMM_{CO} = 6.626\times 10^{8}\ gm$$

Emissions Due to Vehicles manufactured 1995 or before:

Note: Prior to 1996 vehicles were generally classified as either Light Duty Vehicles (LDV) or Light Dut Trucks (LDT)

Recalculated Old Vehicle Distributions

$LDV_{old} := SmC_{old} + LMM_{old}$ $\quad LDV_{old} = 0.8$

$LDT_{old} := SUV_{old}$ $\quad LDT_{old} = 0.2$

x100 percent distribution

1992 to 1995 Emissions Data:

By 1992, all vehicles had to conform to the following Federal standard:

$$LDV\_9295_{CO} := 3.4 \cdot \frac{gm}{mi} \qquad LDV\_9295_{HC} := 0.41 \cdot \frac{gm}{mi} \qquad LDV\_9295_{NOx} := 1.0 \cdot \frac{gm}{mi}$$

$$LDT\_9295_{CO} := 10 \cdot \frac{gm}{mi} \qquad LDT\_9295_{HC} := 0.67 \cdot \frac{gm}{mi} \qquad LDT\_9295_{NOx} := 1.2 \cdot \frac{gm}{mi}$$

1982 - 1991 Emissions Data:

In this time frame, HC were not regulated. Instead Volatile Organic Compounds (VOC) were the standard, and will be considered nearly equivalent to HC's

Vehicles older than 1991 have reached their full usefull life of 10 yrs / 100,000 mi

$$LDV\_8291_{CO} := 4.2 \cdot \frac{gm}{mi} \qquad LDV\_8291_{VOC} := 0.80 \cdot \frac{gm}{mi} \qquad LDV\_8291_{NOx} := 1.0 \frac{gm}{mi}$$

$$LDT\_8291_{CO} := \frac{10 \cdot 8 + 18}{9} \cdot \frac{gm}{mi} \qquad LDT\_8291_{VOC} := 0.80 \cdot \frac{gm}{mi} \qquad LDT\_8291_{NOx} := 1.2 \cdot \frac{gm}{mi}$$

Pre 1982 Data:

$$LDV\_P82_{CO} := \frac{23 \cdot 2 + 39 \cdot 3 + 15 \cdot 5}{10} \cdot \frac{gm}{mi} \qquad LDV\_P82_{NOx} := \frac{3 \cdot 3 + 3.1 \cdot 2 + 2 \cdot 4 + 1 \cdot 2}{11} \cdot \frac{gm}{mi}$$

$$LDV\_P82_{VOC} := \frac{3.4 \cdot 3 + 1.5 \cdot 5 + 0.41 \cdot 2}{10} \cdot \frac{gm}{mi}$$

$$LDT\_P82_{CO} := \frac{39 \cdot 3 + 20 \cdot 5 + 18 \cdot 4}{12} \cdot \frac{gm}{mi} \qquad LDT\_P82_{VOC} := \frac{3.4 \cdot 3 + 2 \cdot 4 + 1.7 \cdot 6}{13} \cdot \frac{gm}{mi}$$

$$LDT\_P82_{NOx} := \frac{3 \cdot 3 + 3.1 \cdot 4 + 2.3 \cdot 6}{13} \cdot \frac{gm}{mi}$$

Emissions Calculations:

1992 - 1995

$LDV9295_{CO} := V_{9295} \cdot (Total\_Worcester\_miles) \cdot LDV\_9295_{CO} \cdot LDC\%$ $LDV9295_{CO} = 1.8 \times 10^{8}\ gm$

$LDT9295_{CO} := V_{9295} \cdot (Total\_Worcester\_miles) \cdot LDT\_9295_{CO} \cdot LDT\%$ $LDT9295_{CO} = 1.324 \times 10^{8}\ gm$

$LDV9295_{NOx} := V_{9295} \cdot (Total\_Worcester\_miles) \cdot LDV\_9295_{NOx} \cdot LDC\%$ $LDV9295_{NOx} = 5.294 \times 10^{7}\ gm$

$LDT9295_{NOx} := V_{9295} \cdot (Total\_Worcester\_miles) \cdot LDT\_9295_{NOx} \cdot LDT\%$ $LDT9295_{NOx} = 1.588 \times 10^{7}\ gm$

$LDV9295_{HC} := V_{9295} \cdot (Total\_Worcester\_miles) \cdot LDV\_9295_{HC} \cdot LDC\%$ $LDV9295_{HC} = 2.171 \times 10^{7}\ gm$

$LDT9295_{HC} := V_{9295} \cdot (Total\_Worcester\_miles) \cdot LDT\_9295_{HC} \cdot LDT\%$ $LDT9295_{HC} = 8.868 \times 10^{6}\ gm$

1982-1991

$LDV8291_{CO} := V_{8291} \cdot (Total\_Worcester\_miles) \cdot LDV\_8291_{CO} \cdot LDC\%$ $LDV8291_{CO} = 1.631 \times 10^{8}\ gm$

$LDT8291_{CO} := V_{8291} \cdot (Total\_Worcester\_miles) \cdot LDT\_8291_{CO} \cdot LDT\%$ $LDT8291_{CO} = 1.057 \times 10^{8}\ gm$

$LDV8291_{NOx} := V_{8291} \cdot (Total\_Worcester\_miles) \cdot LDV\_8291_{NOx} \cdot LDC\%$ $LDV8291_{NOx} = 3.883 \times 10^{7}\ gm$

$LDT8291_{NOx} := V_{8291} \cdot (Total\_Worcester\_miles) \cdot LDT\_8291_{NOx} \cdot LDT\%$ $LDT8291_{NOx} = 1.165 \times 10^{7}\ gm$

$LDV8291_{VOC} := V_{8291} \cdot (Total\_Worcester\_miles) \cdot LDV\_8291_{VOC} \cdot LDC\%$ $LDV8291_{VOC} = 3.106 \times 10^{7}\ gm$

$LDT8291_{VOC} := V_{8291} \cdot (Total\_Worcester\_miles) \cdot LDT\_8291_{VOC} \cdot LDT\%$ $LDT8291_{VOC} = 7.765 \times 10^{6}\ gm$

Pre 1982

$LDVP82_{CO} := V_{P82} \cdot (Total\_Worcester\_miles) \cdot LDV\_P82_{CO} \cdot LDC\%$ $LDVP82_{CO} = 1.26 \times 10^{8}\ gm$

$LDTP82_{CO} := V_{P82} \cdot (Total\_Worcester\_miles) \cdot LDT\_P82_{CO} \cdot LDT\%$ $LDTP82_{CO} = 3.188 \times 10^{7}\ gm$

$LDVP82_{NOx} := V_{P82} \cdot (Total\_Worcester\_miles) \cdot LDV\_P82_{NOx} \cdot LDC\%$ $LDVP82_{NOx} = 1.213 \times 10^{7}\ gm$

$LDTP82_{NOx} := V_{P82} \cdot (Total\_Worcester\_miles) \cdot LDT\_P82_{NOx} \cdot LDT\%$ $LDTP82_{NOx} = 3.584 \times 10^{6}\ gm$

$LDVP82_{VOC} := V_{P82} \cdot (Total\_Worcester\_miles) \cdot LDV\_P82_{VOC} \cdot LDC\%$ $LDVP82_{VOC} = 9.805 \times 10^{6}\ gm$

$LDTP82_{VOC} := V_{P82} \cdot (Total\_Worcester\_miles) \cdot LDT\_P82_{VOC} \cdot LDT\%$ $LDTP82_{VOC} = 2.892 \times 10^{6}\ gm$

Total Emissions of New Vehicles, (English Tons):

Carbon Monoxide:

$$CO_{new} := LMM_{CO} + SmC_{CO} + SUV_{CO}$$

$$CO_{new} = 1409\,ton$$

$LMM_{CO} = 730.4\,ton$

$SmC_{CO} = 332.4\,ton$

$SUV_{CO} = 346.1\,ton$

Nitrous Oxides:

$$NOx_{new} := LMM_{NOx} + SmC_{NOx} + SUV_{NOx}$$

$$NOx_{new} = 114.5\,ton$$

$LMM_{NOx} = 53.1\,ton$

$SmC_{NOx} = 26.4\,ton$

$SUV_{NOx} = 35\,ton$

Hydocarbons:

$$HC_{new} := LMM_{HC} + SmC_{HC} + SUV_{HC}$$

$$HC_{new} = 49.7\,ton$$

$LMM_{HC} = 21.4\,ton$

$SmC_{HC} = 11.2\,ton$

$SUV_{HC} = 17.1\,ton$

Total Emissions:

$$Emissions_{new} := CO_{new} + NOx_{new} + HC_{new}$$

$$Emissions_{new} = 1573.2\,ton$$

Total Emissions of Older Vehicles, (English Tons):

Carbon Monoxide:

$LDV9295_{CO} = 198.4\,ton$ $LDV8291_{CO} = 179.8\,ton$ $LDVP82_{CO} = 138.9\,ton$

$LDT9295_{CO} = 145.9\,ton$ $LDT8291_{CO} = 116.5\,ton$ $LDTP82_{CO} = 35.1\,ton$

$$CO_{old} := LDV9295_{CO} + LDT9295_{CO} + LDV8291_{CO} + LDT8291_{CO} \cdots + LDVP82_{CO} + LDTP82_{CO}$$

Nitrous Oxides:

$LDV9295_{NOx} = 58.4\,ton$ $LDV8291_{NOx} = 42.8\,ton$ $LDVP82_{NOx} = 13.4\,ton$

$LDT9295_{NOx} = 17.5\,ton$ $LDT8291_{NOx} = 12.8\,ton$ $LDTP82_{NOx} = 4\,ton$

$$NOx_{old} := LDV9295_{NOx} + LDT9295_{NOx} + LDV8291_{NOx} + LDT8291_{NOx} \cdots + LDVP82_{NOx} + LDTP82_{NOx}$$

HydroCarbons and Volatile Organic Compounds:

$LDV9295_{HC} = 23.9\,ton$ $LDV8291_{VOC} = 34.2\,ton$ $LDVP82_{VOC} = 10.8\,ton$

$LDT9295_{HC} = 9.8\,ton$ $LDT8291_{VOC} = 8.6\,ton$ $LDTP82_{VOC} = 3.2\,ton$

$$HC_{old} := LDV9295_{HC} + LDT9295_{HC} + LDV8291_{VOC} + LDT8291_{VOC} \cdots + LDVP82_{VOC} + LDTP82_{VOC}$$

Totals for Older Vehicles:

$CO_{old} = 814.6\,ton$ $NOx_{old} = 148.8\,ton$ $HC_{old} = 90.5\,ton$

$Emissions_{old} := CO_{old} + NOx_{old} + HC_{old}$

$Emissions_{old} = 1054\,ton$

Calculate emissions of a population of SLEV

$Number\_of\_SLEV := (0.75)\cdot\left(V\%_{old}\right)\cdot Worcester\_population\cdot Vehicles\_per\_person$

$Commuter\_miles_{SLEV} := (Travel\_distance)\cdot\left(\frac{2}{day}\right)\cdot(Work\_days)\cdot(Number\_of\_SLEV)$

$Commuter\_miles_{SLEV} = 0.304\,billion\_miles$ driven per year

$Avg\_commuter\_miles_{SLEV} := \frac{Commuter\_miles_{SLE}}{Number\_of\_SLEV}$ $Avg\_commuter\_miles_{SLEV} = 3.654 \times 10^{3}\,mi$ per vehicle driven per year

$Weekend\_miles_{SLEV} := \left(\frac{Travel\_distance}{2}\right)\cdot\left(\frac{2}{day}\right)\cdot(Week\_ends)\cdot(Number\_of\_SLEV)$

$Weekend\_miles_{SLEV} = 60.472\,million\_miles$ driven per year

$Avg\_weekend\_miles_{SLEV} := \frac{Weekend\_miles_{SLEV}}{Number\_of\_SLEV}$ $Avg\_weekend\_miles_{SLEV} = 728\,mi$ per venicle driven per year

$Total\_Worcester\_miles_{SLEV} := Weekend\_miles_{SLEV} + Commuter\_miles_{SLEV}$

$Total\_Worcester\_miles_{SLEV} = 0.364\,billion\_miles$ driven per year

$SLEV_{CO} := Total\_Worcester\_miles_{SLEV}\cdot SLEV\_CO$ $SLEV_{CO} = 401.234\,ton$

$SLEV_{HC} := Total\_Worcester\_miles_{SLEV}\cdot SLEV\_HC$ $SLEV_{HC} = 4.012\,ton$

$SLEV_{NOx} := Total\_Worcester\_miles_{SLEV}\cdot SLEV\_NOx$ $SLEV_{NOx} = 8.025\,ton$

$Total\_Emissions := Emissions_{new} + Emissions_{old} + SLEV_{CO} + SLEV_{HC} + SLEV_{NOx}$

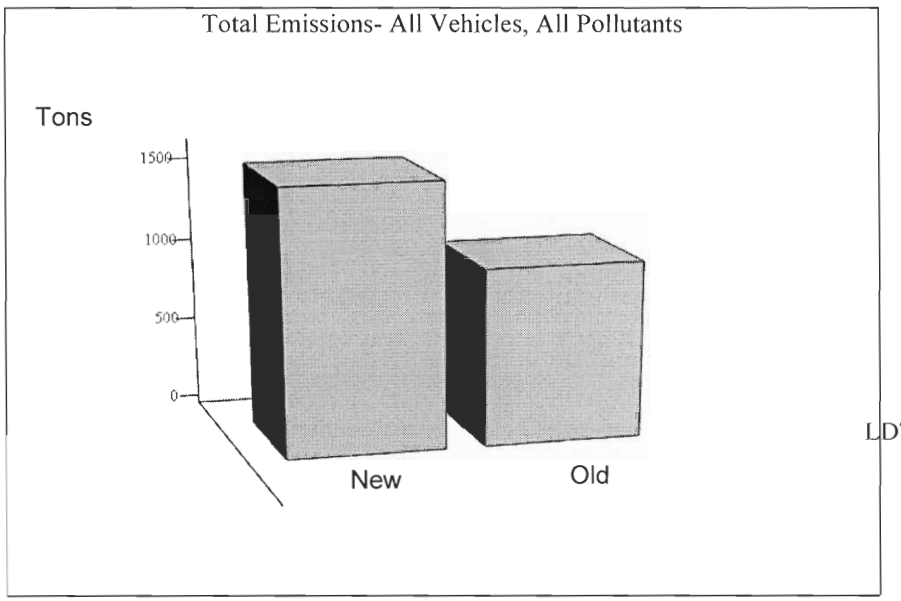
$Total\_Emissions = 3040.4\,ton$

$CO_{Tot} := SLEV_{CO} + CO_{old} + CO_{new}$ $CO_{Tot} = 2624.9\,ton$

$NOx_{Tot} := SLEV_{NOx} + NOx_{old} + NOx_{new}$ $NOx_{Tot} = 271.3\,ton$

$HC_{Tot} := SLEV_{HC} + HC_{old} + HC_{new}$ $HC_{Tot} = 144.2\,ton$

$$Graph1 := \left(\frac{Emissions_{new}}{2000} \quad \frac{Emissions_{old}}{2000} \right)$$



$LDTP82_{VOC} = 12.1$

Replacing 100% of all Vehicles w/Hybrids

billion_miles := $10^9 \cdot mi$

million_miles := $10^6 \cdot mi$

Assumptions:

Vehicles traveling through Worcester Travel an average of 7 miles each

Travel_distance := $7 \cdot mi$

40% of the pollutants in the air come from vehicles

Work_days := $261 \cdot day$

Week_ends := $104 \cdot day$

City Data:

Worcester_population := 254900 people

Vehicles_per_person := 0.79

Percentages of Vehicle Types:

Newer Vehicles:

SUV := 0.275 SmC := 0.21 LMM := 0.51

Older Vehicles:

SUV_{old} := 0.20 SmC_{old} := 0.20 LMM_{old} := 0.60 LDT% := SUV_{old}

LDC% := $SmC_{old} + LMM_{old}$

Age distribution of Vehicles on the Roads:

1996 - 2002 V_{9602} := 0.45

1992 - 1995 V_{9295} := 0.30

1982 - 1991 V_{8291} := 0.22

Pre 1982 V_{P82} := 0.03

Transitional Low Emissions Vehicle Data:

TLEV_NMOG := $0.125 \cdot \frac{gm}{mi}$ TLEV_NOx := $0.4 \cdot \frac{gm}{mi}$

TLEV_CO := $3.4 \cdot \frac{gm}{mi}$ TLEV_HCHO := $0.015 \cdot \frac{gm}{mi}$

TLEV HC := TLEV NMOG + TLEV_HCHO

TLEV_HC = $0.14 \frac{gm}{mi}$

Low Emissions Vehicle Data:

LEV_NMOG := $0.075 \cdot \frac{gm}{mi}$ LEV_NOx := $0.2 \cdot \frac{gm}{mi}$

LEV_CO := $3.4 \cdot \frac{gm}{mi}$ LEV_HCHO := $0.015 \cdot \frac{gm}{mi}$

LEV_HC := LEV_NMOG + LEV_HCHO

LEV_HC = $0.09 \frac{gm}{mi}$

Ultra Low Emissions Vehicle Data:

$$ULEV\_NMOG := 0.04 \cdot \frac{gm}{mi} \qquad ULEV\_NOx := 0.2 \cdot \frac{gm}{mi}$$

$$ULEV\_CO := 1.7 \cdot \frac{gm}{mi} \qquad ULEV\_HCHO := 0.008 \cdot \frac{gm}{mi}$$

$$ULEV\_HC := ULEV\_NMOG + ULEV\_HCHO$$

$$ULEV\_HC = 0.048 \frac{gm}{mi}$$

Super Low Emissions Vehicle Data:

$$SLEV\_CO := 1.0 \cdot \frac{gm}{mi} \qquad SLEV\_HC := 0.01 \cdot \frac{gm}{mi} \qquad SLEV\_NOx := 0.02 \cdot \frac{gm}{mi}$$

Zero Emissions Vehicle Data:

$$ZEV\_CO := 0 \cdot \frac{gm}{mi} \qquad ZEV\_HC := 0 \cdot \frac{gm}{mi} \qquad ZEV\_NOx := 0 \cdot \frac{gm}{mi}$$

Tier 1 Emissions Data:

$$T1\_CO := 4.2 \cdot \frac{gm}{mi} \qquad T1\_HC := 0.31 \cdot \frac{gm}{mi} \qquad T1\_NOx := 0.6 \cdot \frac{gm}{mi}$$

Tabulated Vehicle Distribution for New Vehicles:

$$SUV\_ZEV\_percentage := \frac{0.21}{100} \qquad LMM\_ZEV\_percentage := 0$$

$$SUV\_SLEV\_percentage := \frac{0}{100} \qquad LMM\_SLEV\_percentage := \frac{0}{100}$$

$$SUV\_ULEV\_percentage := \frac{4.5}{100} \qquad LMM\_ULEV\_percentage := \frac{19.13}{100}$$

$$SUV\_LEV\_percentage := \frac{51.82}{100} \qquad LMM\_LEV\_percentage := \frac{70.40}{100}$$

$$SUV\_TLEV\_percentage := \frac{1.5}{100} \qquad LMM\_TLEV\_percentage := \frac{7.94}{100}$$

$$SUV\_T1\_percentage := \frac{41.11}{100} \qquad LMM\_T1\_percentage := \frac{2.17}{100}$$

$$SmC\_ZEV\_percentage := \frac{0.26}{100} \qquad SmC\_LEV\_percentage := \frac{65.17}{100}$$

$$SmC\_SLEV\_percentage := \frac{0}{100} \qquad SmC\_TLEV\_percentage := \frac{9.5}{100}$$

$$SmC\_ULEV\_percentage := \frac{15.04}{100} \qquad SmC\_T1\_percentage := \frac{8.97}{100}$$

Percentages of Each New Vehicle Type Observed on the Road:

SmC_on_road := .2395 LMM_on_road := .5418

SUV_on_road := .2187

Equations:

Number_of_Vehicles := 0.0·Worcester_population·Vehicles_per_person

Number_of_Vehicles = 0

$$\text{Commuter\_miles} := (\text{Travel\_distance})\cdot\left(\frac{2}{\text{day}}\right)\cdot(\text{Work\_days})\cdot(\text{Number\_of\_Vehicles})$$

Commuter_miles = 0 billion_miles driven per year

$$\text{Avg\_commuter\_miles} := \frac{\text{Commuter\_miles}}{\text{Number\_of\_Vehicles}}$$

Avg_commuter_miles = 0 mi per vehicle driven per year

$$\text{Weekend\_miles} := \left(\frac{\text{Travel\_distance}}{2}\right)\cdot\left(\frac{2}{\text{day}}\right)\cdot(\text{Week\_ends})\cdot(\text{Number\_of\_Vehicles})$$

Weekend_miles = 0 million_miles driven per year

$$\text{Avg\_weekend\_miles} := \frac{\text{Weekend\_miles}}{\text{Number\_of\_Vehicles}}$$

Avg_weekend_miles = 0 mi per vehicle driven per year

Total_Worcester_miles := Weekend_miles + Commuter_miles Total_Worcester_miles = 0 billion_miles driven per year

Emissions Due to New SUV's

$$\text{SUV}_{NOx} := V_{9602}\cdot\left[\begin{array}{l}(\text{Total\_Worcester\_miles})\cdot(\text{SUV\_on\_road})\cdot(\text{SUV\_ZEV\_percentage})\cdot(\text{ZEV\_NOx})\ \ldots\\ +(\text{Total\_Worcester\_miles})\cdot(\text{SUV\_on\_road})\cdot(\text{SUV\_SLEV\_percentage})\cdot(\text{SLEV\_NOx})\ \ldots\\ +(\text{Total\_Worcester\_miles})\cdot(\text{SUV\_on\_road})\cdot(\text{SUV\_T1\_percentage})\cdot(\text{T1\_NOx})\ \ldots\\ +(\text{Total\_Worcester\_miles})\cdot(\text{SUV\_on\_road})\cdot(\text{SUV\_TLEV\_percentage})\cdot(\text{TLEV\_NOx})\ \ldots\\ +(\text{Total\_Worcester\_miles})\cdot(\text{SUV\_on\_road})\cdot(\text{SUV\_LEV\_percentage})\cdot(\text{LEV\_NOx})\ \ldots\\ +(\text{Total\_Worcester\_miles})\cdot(\text{SUV\_on\_road})\cdot(\text{SUV\_ULEV\_percentage})\cdot(\text{ULEV\_NOx})\end{array}\right]$$

$\text{SUV}_{NOx} = 0\,\text{gm}$

$$\text{SUV}_{HC} := V_{9602}\cdot\left[\begin{array}{l}(\text{Total\_Worcester\_miles})\cdot(\text{SUV\_on\_road})\cdot(\text{SUV\_ZEV\_percentage})\cdot(\text{ZEV\_HC})\ \ldots\\ +(\text{Total\_Worcester\_miles})\cdot(\text{SUV\_on\_road})\cdot(\text{SUV\_SLEV\_percentage})\cdot(\text{SLEV\_HC})\ \ldots\\ +(\text{Total\_Worcester\_miles})\cdot(\text{SUV\_on\_road})\cdot(\text{SUV\_T1\_percentage})\cdot(\text{T1\_HC})\ \ldots\\ +(\text{Total\_Worcester\_miles})\cdot(\text{SUV\_on\_road})\cdot(\text{SUV\_TLEV\_percentage})\cdot(\text{TLEV\_HC})\ \ldots\\ +(\text{Total\_Worcester\_miles})\cdot(\text{SUV\_on\_road})\cdot(\text{SUV\_LEV\_percentage})\cdot(\text{LEV\_HC})\ \ldots\\ +(\text{Total\_Worcester\_miles})\cdot(\text{SUV\_on\_road})\cdot(\text{SUV\_ULEV\_percentage})\cdot(\text{ULEV\_HC})\end{array}\right]$$

$\text{SUV}_{HC} = 0\,\text{gm}$

$$SUV_{CO} := V_{9602}\cdot\begin{bmatrix} (Total\_Worcester\_miles)\cdot(SUV\_on\_road)\cdot(SUV\_ZEV\_percentage)\cdot(ZEV\_CO) \ldots \\ +(Total\_Worcester\_miles)\cdot(SUV\_on\_road)\cdot(SUV\_SLEV\_percentage)\cdot(SLEV\_CO) \ldots \\ +(Total\_Worcester\_miles)\cdot(SUV\_on\_road)\cdot(SUV\_T1\_percentage)\cdot(T1\_CO) \ldots \\ +(Total\_Worcester\_miles)\cdot(SUV\_on\_road)\cdot(SUV\_TLEV\_percentage)\cdot(TLEV\_CO) \ldots \\ +(Total\_Worcester\_miles)\cdot(SUV\_on\_road)\cdot(SUV\_LEV\_percentage)\cdot(LEV\_CO) \ldots \\ +(Total\_Worcester\_miles)\cdot(SUV\_on\_road)\cdot(SUV\_ULEV\_percentage)\cdot(ULEV\_CO) \end{bmatrix}$$

$$SUV_{CO} = 0\,gm$$

Emissions Due to New Small Cars

$$SmC_{NOx} := V_{9602}\cdot\begin{bmatrix} (Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_ZEV\_percentage)\cdot(ZEV\_NOx) \ldots \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_SLEV\_percentage)\cdot(SLEV\_NOx) \ldots \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_T1\_percentage)\cdot(T1\_NOx) \ldots \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_TLEV\_percentage)\cdot(TLEV\_NOx) \ldots \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_LEV\_percentage)\cdot(LEV\_NOx) \ldots \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_ULEV\_percentage)\cdot(ULEV\_NOx) \end{bmatrix}$$

$$SmC_{NOx} = 0\,gm$$

$$SmC_{HC} := V_{9602}\cdot\begin{bmatrix} (Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_ZEV\_percentage)\cdot(ZEV\_HC) \ldots \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_SLEV\_percentage)\cdot(SLEV\_HC) \ldots \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_T1\_percentage)\cdot(T1\_HC) \ldots \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_TLEV\_percentage)\cdot(TLEV\_HC) \ldots \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_LEV\_percentage)\cdot(LEV\_HC) \ldots \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_ULEV\_percentage)\cdot(ULEV\_HC) \end{bmatrix}$$

$$SmC_{HC} = 0\,gm$$

$$SmC_{CO} := V_{9602}\cdot\begin{bmatrix} (Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_ZEV\_percentage)\cdot(ZEV\_CO) \ldots \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_SLEV\_percentage)\cdot(SLEV\_CO) \ldots \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_T1\_percentage)\cdot(T1\_CO) \ldots \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_TLEV\_percentage)\cdot(TLEV\_CO) \ldots \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_LEV\_percentage)\cdot(LEV\_CO) \ldots \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_ULEV\_percentage)\cdot(ULEV\_CO) \end{bmatrix}$$

$$SmC_{CO} = 0\,gm$$

Emissions Due to New Large-Medium cars and Minivans

$$LMM_{NOx} := V_{9602}\cdot\left[\begin{array}{l}(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_ZEV\_percentage)\cdot(ZEV\_NOx)\ ... \\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_SLEV\_percentage)\cdot(SLEV\_NOx)\ ... \\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_T1\_percentage)\cdot(T1\_NOx)\ ... \\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_TLEV\_percentage)\cdot(TLEV\_NOx)\ ... \\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_LEV\_percentage)\cdot(LEV\_NOx)\ ... \\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_ULEV\_percentage)\cdot(ULEV\_NOx)\end{array}\right]$$

$$LMM_{NOx} = 0\,gm$$

$$LMM_{HC} := V_{9602}\cdot\left[\begin{array}{l}(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_ZEV\_percentage)\cdot(ZEV\_HC)\ ... \\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_SLEV\_percentage)\cdot(SLEV\_HC)\ ... \\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_T1\_percentage)\cdot(T1\_HC)\ ... \\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_TLEV\_percentage)\cdot(TLEV\_HC)\ ... \\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_LEV\_percentage)\cdot(LEV\_HC)\ ... \\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_ULEV\_percentage)\cdot(ULEV\_HC)\end{array}\right]$$

$$LMM_{HC} = 0\,gm$$

$$LMM_{CO} := V_{9602}\cdot\left[\begin{array}{l}(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_ZEV\_percentage)\cdot(ZEV\_CO)\ ... \\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_SLEV\_percentage)\cdot(SLEV\_CO)\ ... \\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_T1\_percentage)\cdot(T1\_CO)\ ... \\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_TLEV\_percentage)\cdot(TLEV\_CO)\ ... \\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_LEV\_percentage)\cdot(LEV\_CO)\ ... \\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_ULEV\_percentage)\cdot(ULEV\_CO)\end{array}\right]$$

$$LMM_{CO} = 0\,gm$$

Emissions Due to Vehicles manufactured 1995 or before:

Note: Prior to 1996 vehicles were generally classified as either Light Duty Vehicles (LDV) or Light Dut Trucks (LDT)

Recalculated Old Vehicle Distributions

$LDV_{old} := SmC_{old} + LMM_{old}$ $\quad LDV_{old} = 0.8$

$LDT_{old} := SUV_{old}$ $\quad LDT_{old} = 0.2$

x100 percent distribution

1992 to 1995 Emissions Data:

By 1992, all vehicles had to conform to the following Federal standard:

$LDV\_9295_{CO} := 3.4 \cdot \frac{gm}{mi}$ $\quad LDV\_9295_{HC} := 0.41 \cdot \frac{gm}{mi}$ $\quad LDV\_9295_{NOx} := 1.0 \cdot \frac{gm}{mi}$

$LDT\_9295_{CO} := 10 \cdot \frac{gm}{mi}$ $\quad LDT\_9295_{HC} := 0.67 \cdot \frac{gm}{mi}$ $\quad LDT\_9295_{NOx} := 1.2 \cdot \frac{gm}{mi}$

1982 - 1991 Emissions Data:

In this time frame, HC were not regulated. Instead Volatile Organic Compounds (VOC) were the standard, and will be considered nearly equivalent to HC's

Vehicles older than 1991 have reached their full usefull life of 10 yrs / 100,000 mi

$LDV\_8291_{CO} := 4.2 \cdot \frac{gm}{mi}$ $\quad LDV\_8291_{VOC} := 0.80 \cdot \frac{gm}{mi}$ $\quad LDV\_8291_{NOx} := 1.0 \frac{gm}{mi}$

$LDT\_8291_{CO} := \frac{10 \cdot 8 + 18}{9} \cdot \frac{gm}{mi}$ $\quad LDT\_8291_{VOC} := 0.80 \cdot \frac{gm}{mi}$ $\quad LDT\_8291_{NOx} := 1.2 \cdot \frac{gm}{mi}$

Pre 1982 Data:

$LDV\_P82_{CO} := \frac{23 \cdot 2 + 39 \cdot 3 + 15 \cdot 5}{10} \cdot \frac{gm}{mi}$ $\quad LDV\_P82_{NOx} := \frac{3 \cdot 3 + 3.1 \cdot 2 + 2 \cdot 4 + 1 \cdot 2}{11} \cdot \frac{gm}{mi}$

$LDV\_P82_{VOC} := \frac{3.4 \cdot 3 + 1.5 \cdot 5 + 0.41 \cdot 2}{10} \cdot \frac{gm}{mi}$

$LDT\_P82_{CO} := \frac{39 \cdot 3 + 20 \cdot 5 + 18 \cdot 4}{12} \cdot \frac{gm}{mi}$ $\quad LDT\_P82_{VOC} := \frac{3.4 \cdot 3 + 2 \cdot 4 + 1.7 \cdot 6}{13} \cdot \frac{gm}{mi}$

$LDT\_P82_{NOx} := \frac{3 \cdot 3 + 3.1 \cdot 4 + 2.3 \cdot 6}{13} \cdot \frac{gm}{mi}$

Emissions Calculations:

1992 - 1995

$LDV9295_{CO} := V_{9295} \cdot (Total\_Worcester\_miles) \cdot LDV\_9295_{CO} \cdot LDC\%$ $LDV9295_{CO} = 0\,gm$

$LDT9295_{CO} := V_{9295} \cdot (Total\_Worcester\_miles) \cdot LDT\_9295_{CO} \cdot LDT\%$ $LDT9295_{CO} = 0\,gm$

$LDV9295_{NOx} := V_{9295} \cdot (Total\_Worcester\_miles) \cdot LDV\_9295_{NOx} \cdot LDC\%$ $LDV9295_{NOx} = 0\,gm$

$LDT9295_{NOx} := V_{9295} \cdot (Total\_Worcester\_miles) \cdot LDT\_9295_{NOx} \cdot LDT\%$ $LDT9295_{NOx} = 0\,gm$

$LDV9295_{HC} := V_{9295} \cdot (Total\_Worcester\_miles) \cdot LDV\_9295_{HC} \cdot LDC\%$ $LDV9295_{HC} = 0\,gm$

$LDT9295_{HC} := V_{9295} \cdot (Total\_Worcester\_miles) \cdot LDT\_9295_{HC} \cdot LDT\%$ $LDT9295_{HC} = 0\,gm$

1982-1991

$LDV8291_{CO} := V_{8291} \cdot (Total\_Worcester\_miles) \cdot LDV\_8291_{CO} \cdot LDC\%$ $LDV8291_{CO} = 0\,gm$

$LDT8291_{CO} := V_{8291} \cdot (Total\_Worcester\_miles) \cdot LDT\_8291_{CO} \cdot LDT\%$ $LDT8291_{CO} = 0\,gm$

$LDV8291_{NOx} := V_{8291} \cdot (Total\_Worcester\_miles) \cdot LDV\_8291_{NOx} \cdot LDC\%$ $LDV8291_{NOx} = 0\,gm$

$LDT8291_{NOx} := V_{8291} \cdot (Total\_Worcester\_miles) \cdot LDT\_8291_{NOx} \cdot LDT\%$ $LDT8291_{NOx} = 0\,gm$

$LDV8291_{VOC} := V_{8291} \cdot (Total\_Worcester\_miles) \cdot LDV\_8291_{VOC} \cdot LDC\%$ $LDV8291_{VOC} = 0\,gm$

$LDT8291_{VOC} := V_{8291} \cdot (Total\_Worcester\_miles) \cdot LDT\_8291_{VOC} \cdot LDT\%$ $LDT8291_{VOC} = 0\,gm$

Pre 1982

$LDVP82_{CO} := V_{P82} \cdot (Total\_Worcester\_miles) \cdot LDV\_P82_{CO} \cdot LDC\%$ $LDVP82_{CO} = 0\,gm$

$LDTP82_{CO} := V_{P82} \cdot (Total\_Worcester\_miles) \cdot LDT\_P82_{CO} \cdot LDT\%$ $LDTP82_{CO} = 0\,gm$

$LDVP82_{NOx} := V_{P82} \cdot (Total\_Worcester\_miles) \cdot LDV\_P82_{NOx} \cdot LDC\%$ $LDVP82_{NOx} = 0\,gm$

$LDTP82_{NOx} := V_{P82} \cdot (Total\_Worcester\_miles) \cdot LDT\_P82_{NOx} \cdot LDT\%$ $LDTP82_{NOx} = 0\,gm$

$LDVP82_{VOC} := V_{P82} \cdot (Total\_Worcester\_miles) \cdot LDV\_P82_{VOC} \cdot LDC\%$ $LDVP82_{VOC} = 0\,gm$

$LDTP82_{VOC} := V_{P82} \cdot (Total\_Worcester\_miles) \cdot LDT\_P82_{VOC} \cdot LDT\%$ $LDTP82_{VOC} = 0\,gm$

Total Emissions of New Vehicles, (English Tons):

Carbon Monoxide:

$$CO_{new} := LMM_{CO} + SmC_{CO} + SUV_{CO}$$

$$CO_{new} = 0\,ton$$

$LMM_{CO} = 0\,ton$

$SmC_{CO} = 0\,ton$

$SUV_{CO} = 0\,ton$

Nitrous Oxides:

$$NOx_{new} := LMM_{NOx} + SmC_{NOx} + SUV_{NOx}$$

$$NOx_{new} = 0\,ton$$

$LMM_{NOx} = 0\,ton$

$SmC_{NOx} = 0\,ton$

$SUV_{NOx} = 0\,ton$

Hydocarbons:

$$HC_{new} := LMM_{HC} + SmC_{HC} + SUV_{HC}$$

$$HC_{new} = 0\,ton$$

$LMM_{HC} = 0\,ton$

$SmC_{HC} = 0\,ton$

$SUV_{HC} = 0\,ton$

Total Emissions:

$$Emissions_{new} := CO_{new} + NOx_{new} + HC_{new}$$

$$Emissions_{new} = 0\,ton$$

Total Emissions of Older Vehicles, (English Tons):

Carbon Monoxide:

$LDV9295_{CO} = 0\,ton$ $LDV8291_{CO} = 0\,ton$ $LDVP82_{CO} = 0\,ton$

$LDT9295_{CO} = 0\,ton$ $LDT8291_{CO} = 0\,ton$ $LDTP82_{CO} = 0\,ton$

$$CO_{old} := LDV9295_{CO} + LDT9295_{CO} + LDV8291_{CO} + LDT8291_{CO} + LDT8291_{CO} \cdots + LDVP82_{CO} + LDTP82_{CO}$$

Nitrous Oxides:

$LDV9295_{NOx} = 0\,ton$ $LDV8291_{NOx} = 0\,ton$ $LDVP82_{NOx} = 0\,ton$

$LDT9295_{NOx} = 0\,ton$ $LDT8291_{NOx} = 0\,ton$ $LDTP82_{NOx} = 0\,ton$

$$NOx_{old} := LDV9295_{NOx} + LDT9295_{NOx} + LDV8291_{NOx} + LDT8291_{NOx} \cdots + LDVP82_{NOx} + LDTP82_{NOx}$$

HydroCarbons and Volatile Organic Compounds:

$LDV9295_{HC} = 0\,ton$ $LDV8291_{VOC} = 0\,ton$ $LDVP82_{VOC} = 0\,ton$

$LDT9295_{HC} = 0\,ton$ $LDT8291_{VOC} = 0\,ton$ $LDTP82_{VOC} = 0\,ton$

$$HC_{old} := LDV9295_{HC} + LDT9295_{HC} + LDV8291_{VOC} + LDT8291_{VOC} \cdots + LDVP82_{VOC} + LDTP82_{VOC}$$

Totals for Older Vehicles:

$CO_{old} = 0\,ton$ $NOx_{old} = 0\,ton$ $HC_{old} = 0\,ton$

$Emissions_{old} := CO_{old} + NOx_{old} + HC_{old}$

$Emissions_{old} = 0\,ton$

Calculate emissions of a population of 100% SLEV

$Number\_of\_SLEV := 1 \cdot Worcester\_population \cdot Vehicles\_per\_person$

$Commuter\_miles_{SLEV} := (Travel\_distance) \cdot \left(\frac{2}{day}\right) \cdot (Work\_days) \cdot (Number\_of\_SLEV)$

$Commuter\_miles_{SLEV} = 0.736\,billion\_miles$ driven per year

$Avg\_commuter\_miles_{SLEV} := \frac{Commuter\_miles_{SLE}}{Number\_of\_SLEV}$ $Avg\_commuter\_miles_{SLEV} = 3.654 \times 10^3\,mi$ per vehicle driven per year

$Weekend\_miles_{SLEV} := \left(\frac{Travel\_distance}{2}\right) \cdot \left(\frac{2}{day}\right) \cdot (Week\_ends) \cdot (Number\_of\_SLEV)$

$Weekend\_miles_{SLEV} = 146.598\,million\_milesven$ per year

$Avg\_weekend\_miles_{SLEV} := \frac{Weekend\_miles_{SLEV}}{Number\_of\_SLEV}$ $Avg\_weekend\_miles_{SLEV} = 728\,mi$ per venicle driven per year

$Total\_Worcester\_miles_{SLEV} := Weekend\_miles_{SLEV} + Commuter\_miles_{SLEV}$

$Total\_Worcester\_miles_{SLEV} = 0.882\,billion\_miles$ driven per year

$SLEV_{CO} := Total\_Worcester\_miles_{SLEV} \cdot SLEV\_CO$ $SLEV_{CO} = 972.688\,ton$

$SLEV_{HC} := Total\_Worcester\_miles_{SLEV} \cdot SLEV\_HC$ $SLEV_{HC} = 9.727\,ton$

$SLEV_{NOx} := Total\_Worcester\_miles_{SLEV} \cdot SLEV\_NOx$ $SLEV_{NOx} = 19.454\,ton$

$Total\_Emissions := Emissions_{new} + Emissions_{old} + SLEV_{CO} + SLEV_{HC} + SLEV_{NOx}$

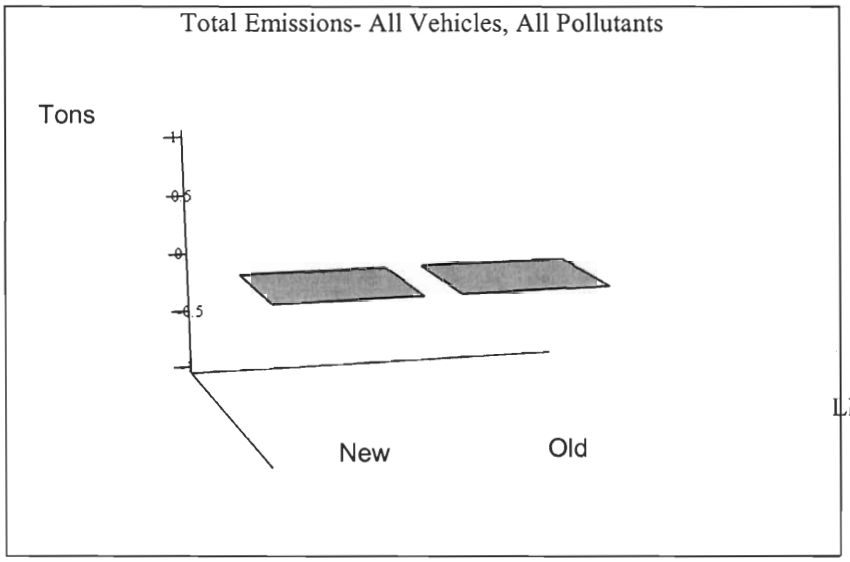
$Total\_Emissions = 1001.9\,ton$

$CO_{Tot} := SLEV_{CO} + CO_{old} + CO_{new}$ $CO_{Tot} = 972.7\,ton$

$NOx_{Tot} := SLEV_{NOx} + NOx_{old} + NOx_{new}$ $NOx_{Tot} = 19.454\,ton$

$HC_{Tot} := SLEV_{HC} + HC_{old} + HC_{new}$ $HC_{Tot} = 9.727\,ton$

$$Graph1 := \left(\frac{Emissions_{new}}{2000} \quad \frac{Emissions_{old}}{2000} \right)$$



$LDTP82_{VOC} = 12.7\,ton$

Replacing 100% of all new Vehicles w/Hybrids

billion_miles := $10^9 \cdot mi$

million_miles := $10^6 \cdot mi$

Assumptions:

Vehicles traveling through Worcester Travel an average of 7 miles each

Travel_distance := $7 \cdot mi$

Work_days := $261 \cdot day$

Week_ends := $104 \cdot day$

City Data:

Worcester_population := 254900 people

Vehicles_per_person := 0.79

Percentages of Vehicle Types:

Newer Vehicles:

SUV := 0.275 SmC := 0.21 LMM := 0.51

Older Vehicles:

SUV_{old} := 0.20 SmC_{old} := 0.20 LMM_{old} := 0.60 LDT% := SUV_{old}

LDC% := $SmC_{old} + LMM_{old}$

Age distribution of Vehicles on the Roads:

1996 - 2002 $V_{9602} := 0.45 \cdot (0.00)$

1992 - 1995 $V_{9295} := 0.30$

1982 - 1991 $V_{8291} := 0.22$

Pre 1982 $V_{P82} := 0.03$

$V\%_{new} := 0.45$

$V\%_{old} := 0.55$ 55% of all worcester vehicles are "old"

Transitional Low Emissions Vehicle Data:

TLEV_NMOG := $0.125 \cdot \frac{gm}{mi}$ TLEV_NOx := $0.4 \cdot \frac{gm}{mi}$

TLEV_CO := $3.4 \cdot \frac{gm}{mi}$ TLEV_HCHO := $0.015 \cdot \frac{gm}{mi}$

TLEV HC := TLEV NMOG + TLEV_HCHO

TLEV_HC = $0.14 \frac{gm}{mi}$

Low Emissions Vehicle Data:

LEV_NMOG := $0.075 \cdot \frac{gm}{mi}$ LEV_NOx := $0.2 \cdot \frac{gm}{mi}$

LEV_CO := $3.4 \cdot \frac{gm}{mi}$ LEV_HCHO := $0.015 \cdot \frac{gm}{mi}$

LEV_HC := LEV_NMOG + LEV_HCHO

LEV_HC = $0.09 \frac{gm}{mi}$

Ultra Low Emissions Vehicle Data:

$$ULEV\_NMOG := 0.04 \cdot \frac{gm}{mi} \qquad ULEV\_NOx := 0.2 \cdot \frac{gm}{mi}$$

$$ULEV\_CO := 1.7 \cdot \frac{gm}{mi} \qquad ULEV\_HCHO := 0.008 \cdot \frac{gm}{mi}$$

$$ULEV\_HC := ULEV\_NMOG + ULEV\_HCHO$$

$$ULEV\_HC = 0.048 \frac{gm}{mi}$$

Super Low Emissions Vehicle Data:

$$SLEV\_CO := 1.0 \cdot \frac{gm}{mi} \qquad SLEV\_HC := 0.01 \cdot \frac{gm}{mi} \qquad SLEV\_NOx := 0.02 \cdot \frac{gm}{mi}$$

Zero Emissions Vehicle Data:

$$ZEV\_CO := 0 \cdot \frac{gm}{mi} \qquad ZEV\_HC := 0 \cdot \frac{gm}{mi} \qquad ZEV\_NOx := 0 \cdot \frac{gm}{mi}$$

Tier 1 Emissions Data:

$$T1\_CO := 4.2 \cdot \frac{gm}{mi} \qquad T1\_HC := 0.31 \cdot \frac{gm}{mi} \qquad T1\_NOx := 0.6 \cdot \frac{gm}{mi}$$

Tabulated Vehicle Distribution for New Vehicles:

$$SUV\_ZEV\_percentage := \frac{0.21}{100} \qquad LMM\_ZEV\_percentage := 0$$

$$SUV\_SLEV\_percentage := \frac{0}{100} \qquad LMM\_SLEV\_percentage := \frac{0}{100}$$

$$SUV\_ULEV\_percentage := \frac{4.5}{100} \qquad LMM\_ULEV\_percentage := \frac{19.13}{100}$$

$$SUV\_LEV\_percentage := \frac{51.82}{100} \qquad LMM\_LEV\_percentage := \frac{70.40}{100}$$

$$SUV\_TLEV\_percentage := \frac{1.5}{100} \qquad LMM\_TLEV\_percentage := \frac{7.94}{100}$$

$$SUV\_T1\_percentage := \frac{41.11}{100} \qquad LMM\_T1\_percentage := \frac{2.17}{100}$$

$$SmC\_ZEV\_percentage := \frac{0.26}{100} \qquad SmC\_LEV\_percentage := \frac{65.17}{100}$$

$$SmC\_SLEV\_percentage := \frac{0}{100} \qquad SmC\_TLEV\_percentage := \frac{9.5}{100}$$

$$SmC\_ULEV\_percentage := \frac{15.04}{100} \qquad SmC\_T1\_percentage := \frac{8.97}{100}$$

Percentages of Each New Vehicle Type Observed on the Road:

SmC_on_road := .2395 LMM_on_road := .5418

SUV_on_road := .2187

Equations:

Number_of_Vehicles := 1.0·Worcester_population·Vehicles_per_person

Number_of_Vehicles = 201371

$$\text{Commuter\_miles} := (\text{Travel\_distance})\cdot\left(\frac{2}{\text{day}}\right)\cdot(\text{Work\_days})\cdot(\text{Number\_of\_Vehicles})$$

Commuter_miles = 0.736 billion_miles driven per year

$$\text{Avg\_commuter\_miles} := \frac{\text{Commuter\_miles}}{\text{Number\_of\_Vehicles}} \qquad \text{Avg\_commuter\_miles} = 3.654 \times 10^{3}\ \text{mi per vehicle driven per year}$$

$$\text{Weekend\_miles} := \left(\frac{\text{Travel\_distance}}{2}\right)\cdot\left(\frac{2}{\text{day}}\right)\cdot(\text{Week\_ends})\cdot(\text{Number\_of\_Vehicles})$$

Weekend_miles = 146.598 million_milesriven per year

$$\text{Avg\_weekend\_miles} := \frac{\text{Weekend\_miles}}{\text{Number\_of\_Vehicles}} \qquad \text{Avg\_weekend\_miles} = 728\ \text{mi per vehicle driven per year}$$

Total_Worcester_miles := Weekend_miles + Commuter_miles Total_Worcester_miles = 0.882 billion_miles driven per year

Emissions Due to New SUV's

$$\text{SUV}_{\text{NOx}} := V_{9602}\cdot\left[\begin{array}{l}(\text{Total\_Worcester\_miles})\cdot(\text{SUV\_on\_road})\cdot(\text{SUV\_ZEV\_percentage})\cdot(\text{ZEV\_NOx})\ \ldots\\ +(\text{Total\_Worcester\_miles})\cdot(\text{SUV\_on\_road})\cdot(\text{SUV\_SLEV\_percentage})\cdot(\text{SLEV\_NOx})\ \ldots\\ +(\text{Total\_Worcester\_miles})\cdot(\text{SUV\_on\_road})\cdot(\text{SUV\_T1\_percentage})\cdot(\text{T1\_NOx})\ \ldots\\ +(\text{Total\_Worcester\_miles})\cdot(\text{SUV\_on\_road})\cdot(\text{SUV\_TLEV\_percentage})\cdot(\text{TLEV\_NOx})\ \ldots\\ +(\text{Total\_Worcester\_miles})\cdot(\text{SUV\_on\_road})\cdot(\text{SUV\_LEV\_percentage})\cdot(\text{LEV\_NOx})\ \ldots\\ +(\text{Total\_Worcester\_miles})\cdot(\text{SUV\_on\_road})\cdot(\text{SUV\_ULEV\_percentage})\cdot(\text{ULEV\_NOx})\end{array}\right]$$

$\text{SUV}_{\text{NOx}} = 0\,\text{gm}$

$$\text{SUV}_{\text{HC}} := V_{9602}\cdot\left[\begin{array}{l}(\text{Total\_Worcester\_miles})\cdot(\text{SUV\_on\_road})\cdot(\text{SUV\_ZEV\_percentage})\cdot(\text{ZEV\_HC})\ \ldots\\ +(\text{Total\_Worcester\_miles})\cdot(\text{SUV\_on\_road})\cdot(\text{SUV\_SLEV\_percentage})\cdot(\text{SLEV\_HC})\ \ldots\\ +(\text{Total\_Worcester\_miles})\cdot(\text{SUV\_on\_road})\cdot(\text{SUV\_T1\_percentage})\cdot(\text{T1\_HC})\ \ldots\\ +(\text{Total\_Worcester\_miles})\cdot(\text{SUV\_on\_road})\cdot(\text{SUV\_TLEV\_percentage})\cdot(\text{TLEV\_HC})\ \ldots\\ +(\text{Total\_Worcester\_miles})\cdot(\text{SUV\_on\_road})\cdot(\text{SUV\_LEV\_percentage})\cdot(\text{LEV\_HC})\ \ldots\\ +(\text{Total\_Worcester\_miles})\cdot(\text{SUV\_on\_road})\cdot(\text{SUV\_ULEV\_percentage})\cdot(\text{ULEV\_HC})\end{array}\right]$$

$\text{SUV}_{\text{HC}} = 0\,\text{gm}$

$$SUV_{CO} := V_{9602}\cdot\left[\begin{array}{l}(Total\_Worcester\_miles)\cdot(SUV\_on\_road)\cdot(SUV\_ZEV\_percentage)\cdot(ZEV\_CO)\ ... \\ +(Total\_Worcester\_miles)\cdot(SUV\_on\_road)\cdot(SUV\_SLEV\_percentage)\cdot(SLEV\_CO)\ ... \\ +(Total\_Worcester\_miles)\cdot(SUV\_on\_road)\cdot(SUV\_T1\_percentage)\cdot(T1\_CO)\ ... \\ +(Total\_Worcester\_miles)\cdot(SUV\_on\_road)\cdot(SUV\_TLEV\_percentage)\cdot(TLEV\_CO)\ ... \\ +(Total\_Worcester\_miles)\cdot(SUV\_on\_road)\cdot(SUV\_LEV\_percentage)\cdot(LEV\_CO)\ ... \\ +(Total\_Worcester\_miles)\cdot(SUV\_on\_road)\cdot(SUV\_ULEV\_percentage)\cdot(ULEV\_CO)\end{array}\right]$$

$$SUV_{CO} = 0\,gm$$

Emissions Due to New Small Cars

$$SmC_{NOx} := V_{9602}\cdot\left[\begin{array}{l}(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_ZEV\_percentage)\cdot(ZEV\_NOx)\ ... \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_SLEV\_percentage)\cdot(SLEV\_NOx)\ ... \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_T1\_percentage)\cdot(T1\_NOx)\ ... \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_TLEV\_percentage)\cdot(TLEV\_NOx)\ ... \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_LEV\_percentage)\cdot(LEV\_NOx)\ ... \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_ULEV\_percentage)\cdot(ULEV\_NOx)\end{array}\right]$$

$$SmC_{NOx} = 0\,gm$$

$$SmC_{HC} := V_{9602}\cdot\left[\begin{array}{l}(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_ZEV\_percentage)\cdot(ZEV\_HC)\ ... \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_SLEV\_percentage)\cdot(SLEV\_HC)\ ... \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_T1\_percentage)\cdot(T1\_HC)\ ... \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_TLEV\_percentage)\cdot(TLEV\_HC)\ ... \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_LEV\_percentage)\cdot(LEV\_HC)\ ... \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_ULEV\_percentage)\cdot(ULEV\_HC)\end{array}\right]$$

$$SmC_{HC} = 0\,gm$$

$$SmC_{CO} := V_{9602}\cdot\left[\begin{array}{l}(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_ZEV\_percentage)\cdot(ZEV\_CO)\ ... \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_SLEV\_percentage)\cdot(SLEV\_CO)\ ... \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_T1\_percentage)\cdot(T1\_CO)\ ... \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_TLEV\_percentage)\cdot(TLEV\_CO)\ ... \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_LEV\_percentage)\cdot(LEV\_CO)\ ... \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_ULEV\_percentage)\cdot(ULEV\_CO)\end{array}\right]$$

$$SmC_{CO} = 0\,gm$$

Emissions Due to New Large-Medium cars and Minivans

$$LMM_{NOx} := V_{9602}\cdot\left[\begin{array}{l}(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_ZEV\_percentage)\cdot(ZEV\_NOx)\ ...\\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_SLEV\_percentage)\cdot(SLEV\_NOx)\ ...\\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_T1\_percentage)\cdot(T1\_NOx)\ ...\\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_TLEV\_percentage)\cdot(TLEV\_NOx)\ ...\\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_LEV\_percentage)\cdot(LEV\_NOx)\ ...\\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_ULEV\_percentage)\cdot(ULEV\_NOx)\end{array}\right]$$

$$LMM_{NOx} = 0\,gm$$

$$LMM_{HC} := V_{9602}\cdot\left[\begin{array}{l}(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_ZEV\_percentage)\cdot(ZEV\_HC)\ ...\\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_SLEV\_percentage)\cdot(SLEV\_HC)\ ...\\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_T1\_percentage)\cdot(T1\_HC)\ ...\\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_TLEV\_percentage)\cdot(TLEV\_HC)\ ...\\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_LEV\_percentage)\cdot(LEV\_HC)\ ...\\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_ULEV\_percentage)\cdot(ULEV\_HC)\end{array}\right]$$

$$LMM_{HC} = 0\,gm$$

$$LMM_{CO} := V_{9602}\cdot\left[\begin{array}{l}(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_ZEV\_percentage)\cdot(ZEV\_CO)\ ...\\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_SLEV\_percentage)\cdot(SLEV\_CO)\ ...\\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_T1\_percentage)\cdot(T1\_CO)\ ...\\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_TLEV\_percentage)\cdot(TLEV\_CO)\ ...\\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_LEV\_percentage)\cdot(LEV\_CO)\ ...\\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_ULEV\_percentage)\cdot(ULEV\_CO)\end{array}\right]$$

$$LMM_{CO} = 0\,gm$$

Emissions Due to Vehicles manufactured 1995 or before:

Note: Prior to 1996 vehicles were generally classified as either Light Duty Vehicles (LDV) or Light Dut Trucks (LDT)

Recalculated Old Vehicle Distributions

$LDV_{old} := SmC_{old} + LMM_{old}$ $LDV_{old} = 0.8$

$LDT_{old} := SUV_{old}$ $LDT_{old} = 0.2$

x100 percent distribution

1992 to 1995 Emissions Data:

By 1992, all vehicles had to conform to the following Federal standard:

$LDV\_9295_{CO} := 3.4 \cdot \frac{gm}{mi}$ $LDV\_9295_{HC} := 0.41 \cdot \frac{gm}{mi}$ $LDV\_9295_{NOx} := 1.0 \cdot \frac{gm}{mi}$

$LDT\_9295_{CO} := 10 \cdot \frac{gm}{mi}$ $LDT\_9295_{HC} := 0.67 \cdot \frac{gm}{mi}$ $LDT\_9295_{NOx} := 1.2 \cdot \frac{gm}{mi}$

1982 - 1991 Emissions Data:

In this time frame, HC were not regulated. Instead Volatile Organic Compounds (VOC) were the standard, and will be considered nearly equivalent to HC's

Vehicles older than 1991 have reached their full usefull life of 10 yrs / 100,000 mi

$LDV\_8291_{CO} := 4.2 \cdot \frac{gm}{mi}$ $LDV\_8291_{VOC} := 0.80 \cdot \frac{gm}{mi}$ $LDV\_8291_{NOx} := 1.0 \frac{gm}{mi}$

$LDT\_8291_{CO} := \frac{10 \cdot 8 + 18}{9} \cdot \frac{gm}{mi}$ $LDT\_8291_{VOC} := 0.80 \cdot \frac{gm}{mi}$ $LDT\_8291_{NOx} := 1.2 \cdot \frac{gm}{mi}$

Pre 1982 Data:

$LDV\_P82_{CO} := \frac{23 \cdot 2 + 39 \cdot 3 + 15 \cdot 5}{10} \cdot \frac{gm}{mi}$ $LDV\_P82_{NOx} := \frac{3 \cdot 3 + 3.1 \cdot 2 + 2 \cdot 4 + 1 \cdot 2}{11} \cdot \frac{gm}{mi}$

$LDV\_P82_{VOC} := \frac{3.4 \cdot 3 + 1.5 \cdot 5 + 0.41 \cdot 2}{10} \cdot \frac{gm}{mi}$

$LDT\_P82_{CO} := \frac{39 \cdot 3 + 20 \cdot 5 + 18 \cdot 4}{12} \cdot \frac{gm}{mi}$ $LDT\_P82_{VOC} := \frac{3.4 \cdot 3 + 2 \cdot 4 + 1.7 \cdot 6}{13} \cdot \frac{gm}{mi}$

$LDT\_P82_{NOx} := \frac{3 \cdot 3 + 3.1 \cdot 4 + 2.3 \cdot 6}{13} \cdot \frac{gm}{mi}$

Emissions Calculations:

1992 - 1995

$LDV9295_{CO} := V_{9295} \cdot (Total\_Worcester\_miles) \cdot LDV\_9295_{CO} \cdot LDC\%$ $LDV9295_{CO} = 7.2 \times 10^{8}\ gm$

$LDT9295_{CO} := V_{9295} \cdot (Total\_Worcester\_miles) \cdot LDT\_9295_{CO} \cdot LDT\%$ $LDT9295_{CO} = 5.294 \times 10^{8}\ gm$

$LDV9295_{NOx} := V_{9295} \cdot (Total\_Worcester\_miles) \cdot LDV\_9295_{NOx} \cdot LDC\%$ $LDV9295_{NOx} = 2.118 \times 10^{8}\ gm$

$LDT9295_{NOx} := V_{9295} \cdot (Total\_Worcester\_miles) \cdot LDT\_9295_{NOx} \cdot LDT\%$ $LDT9295_{NOx} = 6.353 \times 10^{7}\ gm$

$LDV9295_{HC} := V_{9295} \cdot (Total\_Worcester\_miles) \cdot LDV\_9295_{HC} \cdot LDC\%$ $LDV9295_{HC} = 8.683 \times 10^{7}\ gm$

$LDT9295_{HC} := V_{9295} \cdot (Total\_Worcester\_miles) \cdot LDT\_9295_{HC} \cdot LDT\%$ $LDT9295_{HC} = 3.547 \times 10^{7}\ gm$

1982-1991

$LDV8291_{CO} := V_{8291} \cdot (Total\_Worcester\_miles) \cdot LDV\_8291_{CO} \cdot LDC\%$ $LDV8291_{CO} = 6.523 \times 10^{8}\ gm$

$LDT8291_{CO} := V_{8291} \cdot (Total\_Worcester\_miles) \cdot LDT\_8291_{CO} \cdot LDT\%$ $LDT8291_{CO} = 4.228 \times 10^{8}\ gm$

$LDV8291_{NOx} := V_{8291} \cdot (Total\_Worcester\_miles) \cdot LDV\_8291_{NOx} \cdot LDC\%$ $LDV8291_{NOx} = 1.553 \times 10^{8}\ gm$

$LDT8291_{NOx} := V_{8291} \cdot (Total\_Worcester\_miles) \cdot LDT\_8291_{NOx} \cdot LDT\%$ $LDT8291_{NOx} = 4.659 \times 10^{7}\ gm$

$LDV8291_{VOC} := V_{8291} \cdot (Total\_Worcester\_miles) \cdot LDV\_8291_{VOC} \cdot LDC\%$ $LDV8291_{VOC} = 1.242 \times 10^{8}\ gm$

$LDT8291_{VOC} := V_{8291} \cdot (Total\_Worcester\_miles) \cdot LDT\_8291_{VOC} \cdot LDT\%$ $LDT8291_{VOC} = 3.106 \times 10^{7}\ gm$

Pre 1982

$LDVP82_{CO} := V_{P82} \cdot (Total\_Worcester\_miles) \cdot LDV\_P82_{CO} \cdot LDC\%$ $LDVP82_{CO} = 5.04 \times 10^{8}\ gm$

$LDTP82_{CO} := V_{P82} \cdot (Total\_Worcester\_miles) \cdot LDT\_P82_{CO} \cdot LDT\%$ $LDTP82_{CO} = 1.275 \times 10^{8}\ gm$

$LDVP82_{NOx} := V_{P82} \cdot (Total\_Worcester\_miles) \cdot LDV\_P82_{NOx} \cdot LDC\%$ $LDVP82_{NOx} = 4.852 \times 10^{7}\ gm$

$LDTP82_{NOx} := V_{P82} \cdot (Total\_Worcester\_miles) \cdot LDT\_P82_{NOx} \cdot LDT\%$ $LDTP82_{NOx} = 1.434 \times 10^{7}\ gm$

$LDVP82_{VOC} := V_{P82} \cdot (Total\_Worcester\_miles) \cdot LDV\_P82_{VOC} \cdot LDC\%$ $LDVP82_{VOC} = 3.922 \times 10^{7}\ gm$

$LDTP82_{VOC} := V_{P82} \cdot (Total\_Worcester\_miles) \cdot LDT\_P82_{VOC} \cdot LDT\%$ $LDTP82_{VOC} = 1.157 \times 10^{7}\ gm$

Total Emissions of New Vehicles, (English Tons):

Carbon Monoxide:

$$CO_{new} := LMM_{CO} + SmC_{CO} + SUV_{CO} \qquad LMM_{CO} = 0\,ton$$

$$SmC_{CO} = 0\,ton$$

$$CO_{new} = 0\,ton \qquad SUV_{CO} = 0\,ton$$

Nitrous Oxides:

$$NOx_{new} := LMM_{NOx} + SmC_{NOx} + SUV_{NOx} \qquad LMM_{NOx} = 0\,ton$$

$$SmC_{NOx} = 0\,ton$$

$$NOx_{new} = 0\,ton \qquad SUV_{NOx} = 0\,ton$$

Hydocarbons:

$$HC_{new} := LMM_{HC} + SmC_{HC} + SUV_{HC} \qquad LMM_{HC} = 0\,ton$$

$$SmC_{HC} = 0\,ton$$

$$HC_{new} = 0\,ton \qquad SUV_{HC} = 0\,ton$$

Total Emissions:

$$Emissions_{new} := CO_{new} + NOx_{new} + HC_{new}$$

$$Emissions_{new} = 0\,ton$$

Total Emissions of Older Vehicles, (English Tons):

Carbon Monoxide:

$LDV9295_{CO} = 793.7\,ton$ $LDV8291_{CO} = 719\,ton$ $LDVP82_{CO} = 555.6\,ton$

$LDT9295_{CO} = 583.6\,ton$ $LDT8291_{CO} = 466\,ton$ $LDTP82_{CO} = 140.6\,ton$

$$CO_{old} := LDV9295_{CO} + LDT9295_{CO} + LDV8291_{CO} + LDT8291_{CO} \ldots + LDVP82_{CO} + LDTP82_{CO}$$

Nitrous Oxides:

$LDV9295_{NOx} = 233.4\,ton$ $LDV8291_{NOx} = 171.2\,ton$ $LDVP82_{NOx} = 53.5\,ton$

$LDT9295_{NOx} = 70\,ton$ $LDT8291_{NOx} = 51.4\,ton$ $LDTP82_{NOx} = 15.8\,ton$

$$NOx_{old} := LDV9295_{NOx} + LDT9295_{NOx} + LDV8291_{NOx} + LDT8291_{NOx} \ldots + LDVP82_{NOx} + LDTP82_{NOx}$$

HydroCarbons and Volatile Organic Compounds:

$LDV9295_{HC} = 95.7\,ton$ $LDV8291_{VOC} = 137\,ton$ $LDVP82_{VOC} = 43.2\,ton$

$LDT9295_{HC} = 39.1\,ton$ $LDT8291_{VOC} = 34.2\,ton$ $LDTP82_{VOC} = 12.7\,ton$

$$HC_{old} := LDV9295_{HC} + LDT9295_{HC} + LDV8291_{VOC} + LDT8291_{VOC} \ldots + LDVP82_{VOC} + LDTP82_{VOC}$$

Totals for Older Vehicles:

$CO_{old} = 3258.5\,ton$ $NOx_{old} = 595.3\,ton$ $HC_{old} = 362\,ton$

$Emissions_{old} := CO_{old} + NOx_{old} + HC_{old}$

$Emissions_{old} = 4215.8\,ton$

Calculate emissions of a population of SLEV

$Number\_of\_SLEV := (1.0)\cdot\left(V\%_{new}\right)\cdot Worcester\_population\cdot Vehicles\_per\_person$

$Commuter\_miles_{SLEV} := (Travel\_distance)\cdot\left(\frac{2}{day}\right)\cdot(Work\_days)\cdot(Number\_of\_SLEV)$

$Commuter\_miles_{SLEV} = 0.331\,billion\_miles$ driven per year

$Avg\_commuter\_miles_{SLEV} := \frac{Commuter\_miles_{SLE}}{Number\_of\_SLEV}$ $Avg\_commuter\_miles_{SLEV} = 3.654 \times 10^{3}\,mi$ per vehicle driven per year

$Weekend\_miles_{SLEV} := \left(\frac{Travel\_distance}{2}\right)\cdot\left(\frac{2}{day}\right)\cdot(Week\_ends)\cdot(Number\_of\_SLEV)$

$Weekend\_miles_{SLEV} = 65.969\,million\_miles$ driven per year

$Avg\_weekend\_miles_{SLEV} := \frac{Weekend\_miles_{SLEV}}{Number\_of\_SLEV}$ $Avg\_weekend\_miles_{SLEV} = 728\,mi$ per venicle driven per year

$Total\_Worcester\_miles_{SLEV} := Weekend\_miles_{SLEV} + Commuter\_miles_{SLEV}$

$Total\_Worcester\_miles_{SLEV} = 0.397\,billion\_miles$ driven per year

$SLEV_{CO} := Total\_Worcester\_miles_{SLEV}\cdot SLEV\_CO$ $SLEV_{CO} = 437.71\,ton$

$SLEV_{HC} := Total\_Worcester\_miles_{SLEV}\cdot SLEV\_HC$ $SLEV_{HC} = 4.377\,ton$

$SLEV_{NOx} := Total\_Worcester\_miles_{SLEV}\cdot SLEV\_NOx$ $SLEV_{NOx} = 8.754\,ton$

$Total\_Emissions := Emissions_{new} + Emissions_{old} + SLEV_{CO} + SLEV_{HC} + SLEV_{NOx}$

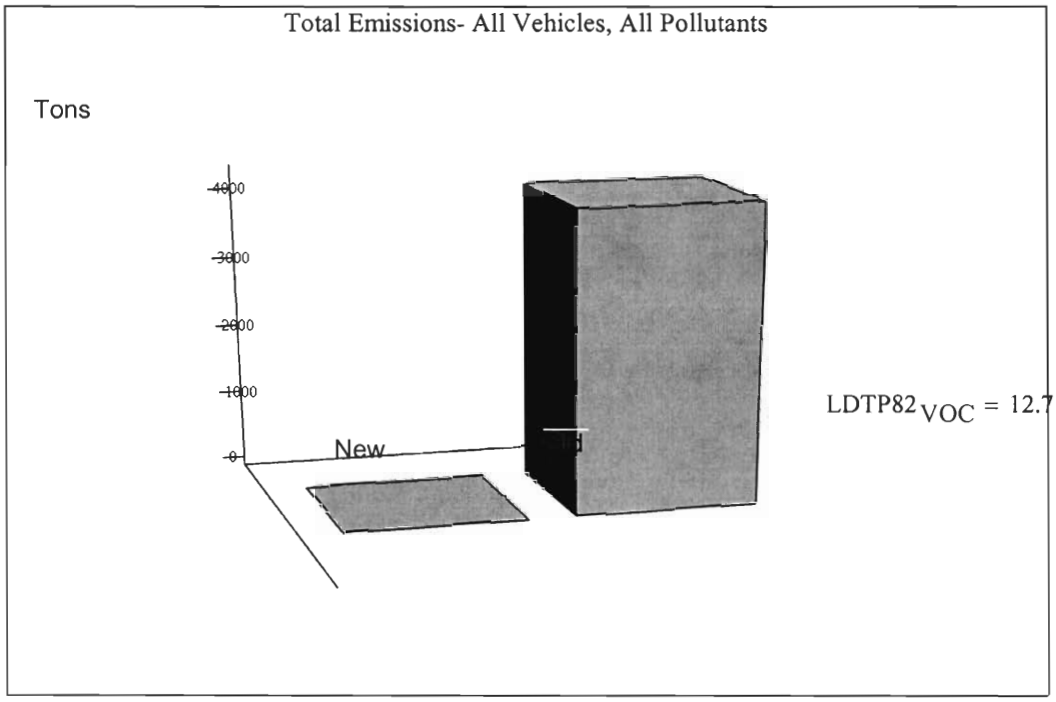
$Total\_Emissions = 4666.7\,ton$

$CO_{Tot} := SLEV_{CO} + CO_{old} + CO_{new}$ $CO_{Tot} = 3696.2\,ton$

$NOx_{Tot} := SLEV_{NOx} + NOx_{old} + NOx_{new}$ $NOx_{Tot} = 604.1\,ton$

$HC_{Tot} := SLEV_{HC} + HC_{old} + HC_{new}$ $HC_{Tot} = 366.4\,ton$

$$Graph1 := \left(\frac{Emissions_{new}}{2000} \quad \frac{Emissions_{old}}{2000} \right)$$



$LDTP82_{VOC} = 12.7\,ton$

Replacing 100% of all old Vehicles w/Hybrids

billion_miles := $10^9 \cdot mi$

million_miles := $10^6 \cdot mi$

Assumptions:

Vehicles traveling through Worcester Travel an average of 7 miles each

Travel_distance := $7 \cdot mi$

Work_days := $261 \cdot day$

Week_ends := $104 \cdot day$

City Data:

Worcester_population := 254900 people

Vehicles_per_person := 0.79

Percentages of Vehicle Types:

Newer Vehicles:

SUV := 0.275 SmC := 0.21 LMM := 0.51

Older Vehicles:

SUV_{old} := 0.20 SmC_{old} := 0.20 LMM_{old} := 0.60 LDT% := SUV_{old}

LDC% := $SmC_{old} + LMM_{old}$

Age distribution of Vehicles on the Roads:

1996 - 2002 V_{9602} := 0.45

1992 - 1995 $V_{9295} := 0.30 \cdot (0.0)$

1982 - 1991 $V_{8291} := 0.22(0.0)$

Pre 1982 $V_{P82} := 0.03 \cdot (0.0)$

$V\%_{old}$:= 0.55 55% of all worcester vehicles are "old"

Transitional Low Emissions Vehicle Data:

TLEV_NMOG := $0.125 \cdot \frac{gm}{mi}$ TLEV_NOx := $0.4 \cdot \frac{gm}{mi}$

TLEV_CO := $3.4 \cdot \frac{gm}{mi}$ TLEV_HCHO := $0.015 \cdot \frac{gm}{mi}$

TLEV HC := TLEV NMOG + TLEV_HCHO

TLEV_HC = $0.14 \frac{gm}{mi}$

Low Emissions Vehicle Data:

LEV_NMOG := $0.075 \cdot \frac{gm}{mi}$ LEV_NOx := $0.2 \cdot \frac{gm}{mi}$

LEV_CO := $3.4 \cdot \frac{gm}{mi}$ LEV_HCHO := $0.015 \cdot \frac{gm}{mi}$

LEV_HC := LEV_NMOG + LEV_HCHO

LEV_HC = $0.09 \frac{gm}{mi}$

Ultra Low Emissions Vehicle Data:

$$ULEV\_NMOG := 0.04 \cdot \frac{gm}{mi} \qquad ULEV\_NOx := 0.2 \cdot \frac{gm}{mi}$$

$$ULEV\_CO := 1.7 \cdot \frac{gm}{mi} \qquad ULEV\_HCHO := 0.008 \cdot \frac{gm}{mi}$$

$$ULEV\_HC := ULEV\_NMOG + ULEV\_HCHO$$

$$ULEV\_HC = 0.048 \frac{gm}{mi}$$

Super Low Emissions Vehicle Data:

$$SLEV\_CO := 1.0 \cdot \frac{gm}{mi} \qquad SLEV\_HC := 0.01 \cdot \frac{gm}{mi} \qquad SLEV\_NOx := 0.02 \cdot \frac{gm}{mi}$$

Zero Emissions Vehicle Data:

$$ZEV\_CO := 0 \cdot \frac{gm}{mi} \qquad ZEV\_HC := 0 \cdot \frac{gm}{mi} \qquad ZEV\_NOx := 0 \cdot \frac{gm}{mi}$$

Tier 1 Emissions Data:

$$T1\_CO := 4.2 \cdot \frac{gm}{mi} \qquad T1\_HC := 0.31 \cdot \frac{gm}{mi} \qquad T1\_NOx := 0.6 \cdot \frac{gm}{mi}$$

Tabulated Vehicle Distribution for New Vehicles:

$$SUV\_ZEV\_percentage := \frac{0.21}{100} \qquad LMM\_ZEV\_percentage := 0$$

$$SUV\_SLEV\_percentage := \frac{0}{100} \qquad LMM\_SLEV\_percentage := \frac{0}{100}$$

$$SUV\_ULEV\_percentage := \frac{4.5}{100} \qquad LMM\_ULEV\_percentage := \frac{19.13}{100}$$

$$SUV\_LEV\_percentage := \frac{51.82}{100} \qquad LMM\_LEV\_percentage := \frac{70.40}{100}$$

$$SUV\_TLEV\_percentage := \frac{1.5}{100} \qquad LMM\_TLEV\_percentage := \frac{7.94}{100}$$

$$SUV\_T1\_percentage := \frac{41.11}{100} \qquad LMM\_T1\_percentage := \frac{2.17}{100}$$

$$SmC\_ZEV\_percentage := \frac{0.26}{100} \qquad SmC\_LEV\_percentage := \frac{65.17}{100}$$

$$SmC\_SLEV\_percentage := \frac{0}{100} \qquad SmC\_TLEV\_percentage := \frac{9.5}{100}$$

$$SmC\_ULEV\_percentage := \frac{15.04}{100} \qquad SmC\_T1\_percentage := \frac{8.97}{100}$$

Percentages of Each New Vehicle Type Observed on the Road:

SmC_on_road := .2395 LMM_on_road := .5418

SUV_on_road := .2187

Equations:

Number_of_Vehicles := 1.0·Worcester_population·Vehicles_per_person

Number_of_Vehicles = 201371

$$\text{Commuter\_miles} := (\text{Travel\_distance})\cdot\left(\frac{2}{\text{day}}\right)\cdot(\text{Work\_days})\cdot(\text{Number\_of\_Vehicles})$$

Commuter_miles = 0.736 billion_miles driven per year

$$\text{Avg\_commuter\_miles} := \frac{\text{Commuter\_miles}}{\text{Number\_of\_Vehicles}} \qquad \text{Avg\_commuter\_miles} = 3.654\times10^{3}\ \frac{\text{mi}}{\text{per vehicle driven per year}}$$

$$\text{Weekend\_miles} := \left(\frac{\text{Travel\_distance}}{2}\right)\cdot\left(\frac{2}{\text{day}}\right)\cdot(\text{Week\_ends})\cdot(\text{Number\_of\_Vehicles})$$

Weekend_miles = 146.598 million_milesriven per year

$$\text{Avg\_weekend\_miles} := \frac{\text{Weekend\_miles}}{\text{Number\_of\_Vehicles}} \qquad \text{Avg\_weekend\_miles} = 728\ \frac{\text{mi}}{\text{per vehicle driven per year}}$$

Total_Worcester_miles := Weekend_miles + Commuter_miles Total_Worcester_miles = 0.882 billion_miles driven per year

Emissions Due to New SUV's

$$\text{SUV}_{\text{NOx}} := V_{9602}\cdot\left[\begin{array}{l}(\text{Total\_Worcester\_miles})\cdot(\text{SUV\_on\_road})\cdot(\text{SUV\_ZEV\_percentage})\cdot(\text{ZEV\_NOx})\ \ldots\\ +(\text{Total\_Worcester\_miles})\cdot(\text{SUV\_on\_road})\cdot(\text{SUV\_SLEV\_percentage})\cdot(\text{SLEV\_NOx})\ \ldots\\ +(\text{Total\_Worcester\_miles})\cdot(\text{SUV\_on\_road})\cdot(\text{SUV\_T1\_percentage})\cdot(\text{T1\_NOx})\ \ldots\\ +(\text{Total\_Worcester\_miles})\cdot(\text{SUV\_on\_road})\cdot(\text{SUV\_TLEV\_percentage})\cdot(\text{TLEV\_NOx})\ \ldots\\ +(\text{Total\_Worcester\_miles})\cdot(\text{SUV\_on\_road})\cdot(\text{SUV\_LEV\_percentage})\cdot(\text{LEV\_NOx})\ \ldots\\ +(\text{Total\_Worcester\_miles})\cdot(\text{SUV\_on\_road})\cdot(\text{SUV\_ULEV\_percentage})\cdot(\text{ULEV\_NOx})\end{array}\right]$$

$$\text{SUV}_{\text{NOx}} = 3.172\times10^{7}\ \text{gm}$$

$$\text{SUV}_{\text{HC}} := V_{9602}\cdot\left[\begin{array}{l}(\text{Total\_Worcester\_miles})\cdot(\text{SUV\_on\_road})\cdot(\text{SUV\_ZEV\_percentage})\cdot(\text{ZEV\_HC})\ \ldots\\ +(\text{Total\_Worcester\_miles})\cdot(\text{SUV\_on\_road})\cdot(\text{SUV\_SLEV\_percentage})\cdot(\text{SLEV\_HC})\ \ldots\\ +(\text{Total\_Worcester\_miles})\cdot(\text{SUV\_on\_road})\cdot(\text{SUV\_T1\_percentage})\cdot(\text{T1\_HC})\ \ldots\\ +(\text{Total\_Worcester\_miles})\cdot(\text{SUV\_on\_road})\cdot(\text{SUV\_TLEV\_percentage})\cdot(\text{TLEV\_HC})\ \ldots\\ +(\text{Total\_Worcester\_miles})\cdot(\text{SUV\_on\_road})\cdot(\text{SUV\_LEV\_percentage})\cdot(\text{LEV\_HC})\ \ldots\\ +(\text{Total\_Worcester\_miles})\cdot(\text{SUV\_on\_road})\cdot(\text{SUV\_ULEV\_percentage})\cdot(\text{ULEV\_HC})\end{array}\right]$$

$$\text{SUV}_{\text{HC}} = 1.549\times10^{7}\ \text{gm}$$

$$SUV_{CO} := V_{9602}\cdot\begin{bmatrix} (Total\_Worcester\_miles)\cdot(SUV\_on\_road)\cdot(SUV\_ZEV\_percentage)\cdot(ZEV\_CO) \ldots \\ +(Total\_Worcester\_miles)\cdot(SUV\_on\_road)\cdot(SUV\_SLEV\_percentage)\cdot(SLEV\_CO) \ldots \\ +(Total\_Worcester\_miles)\cdot(SUV\_on\_road)\cdot(SUV\_T1\_percentage)\cdot(T1\_CO) \ldots \\ +(Total\_Worcester\_miles)\cdot(SUV\_on\_road)\cdot(SUV\_TLEV\_percentage)\cdot(TLEV\_CO) \ldots \\ +(Total\_Worcester\_miles)\cdot(SUV\_on\_road)\cdot(SUV\_LEV\_percentage)\cdot(LEV\_CO) \ldots \\ +(Total\_Worcester\_miles)\cdot(SUV\_on\_road)\cdot(SUV\_ULEV\_percentage)\cdot(ULEV\_CO) \end{bmatrix}$$

$$SUV_{CO} = 3.14 \times 10^{8}\,gm$$

Emissions Due to New Small Cars

$$SmC_{NOx} := V_{9602}\cdot\begin{bmatrix} (Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_ZEV\_percentage)\cdot(ZEV\_NOx) \ldots \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_SLEV\_percentage)\cdot(SLEV\_NOx) \ldots \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_T1\_percentage)\cdot(T1\_NOx) \ldots \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_TLEV\_percentage)\cdot(TLEV\_NOx) \ldots \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_LEV\_percentage)\cdot(LEV\_NOx) \ldots \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_ULEV\_percentage)\cdot(ULEV\_NOx) \end{bmatrix}$$

$$SmC_{NOx} = 2.399 \times 10^{7}\,gm$$

$$SmC_{HC} := V_{9602}\cdot\begin{bmatrix} (Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_ZEV\_percentage)\cdot(ZEV\_HC) \ldots \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_SLEV\_percentage)\cdot(SLEV\_HC) \ldots \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_T1\_percentage)\cdot(T1\_HC) \ldots \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_TLEV\_percentage)\cdot(TLEV\_HC) \ldots \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_LEV\_percentage)\cdot(LEV\_HC) \ldots \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_ULEV\_percentage)\cdot(ULEV\_HC) \end{bmatrix}$$

$$SmC_{HC} = 1.017 \times 10^{7}\,gm$$

$$SmC_{CO} := V_{9602}\cdot\begin{bmatrix} (Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_ZEV\_percentage)\cdot(ZEV\_CO) \ldots \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_SLEV\_percentage)\cdot(SLEV\_CO) \ldots \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_T1\_percentage)\cdot(T1\_CO) \ldots \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_TLEV\_percentage)\cdot(TLEV\_CO) \ldots \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_LEV\_percentage)\cdot(LEV\_CO) \ldots \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_ULEV\_percentage)\cdot(ULEV\_CO) \end{bmatrix}$$

$$SmC_{CO} = 3.016 \times 10^{8}\,gm$$

Emissions Due to New Large-Medium cars and Minivans

$$LMM_{NOx} := V_{9602}\cdot\left[\begin{array}{l}(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_ZEV\_percentage)\cdot(ZEV\_NOx)\ ...\\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_SLEV\_percentage)\cdot(SLEV\_NOx)\ ...\\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_T1\_percentage)\cdot(T1\_NOx)\ ...\\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_TLEV\_percentage)\cdot(TLEV\_NOx)\ ...\\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_LEV\_percentage)\cdot(LEV\_NOx)\ ...\\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_ULEV\_percentage)\cdot(ULEV\_NOx)\end{array}\right]$$

$$LMM_{NOx} = 4.816\times 10^{7}\,gm$$

$$LMM_{HC} := V_{9602}\cdot\left[\begin{array}{l}(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_ZEV\_percentage)\cdot(ZEV\_HC)\ ...\\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_SLEV\_percentage)\cdot(SLEV\_HC)\ ...\\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_T1\_percentage)\cdot(T1\_HC)\ ...\\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_TLEV\_percentage)\cdot(TLEV\_HC)\ ...\\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_LEV\_percentage)\cdot(LEV\_HC)\ ...\\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_ULEV\_percentage)\cdot(ULEV\_HC)\end{array}\right]$$

$$LMM_{HC} = 1.945\times 10^{7}\,gm$$

$$LMM_{CO} := V_{9602}\cdot\left[\begin{array}{l}(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_ZEV\_percentage)\cdot(ZEV\_CO)\ ...\\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_SLEV\_percentage)\cdot(SLEV\_CO)\ ...\\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_T1\_percentage)\cdot(T1\_CO)\ ...\\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_TLEV\_percentage)\cdot(TLEV\_CO)\ ...\\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_LEV\_percentage)\cdot(LEV\_CO)\ ...\\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_ULEV\_percentage)\cdot(ULEV\_CO)\end{array}\right]$$

$$LMM_{CO} = 6.626\times 10^{8}\,gm$$

Emissions Due to Vehicles manufactured 1995 or before:

Note: Prior to 1996 vehicles were generally classified as either Light Duty Vehicles (LDV) or Light Dut Trucks (LDT)

Recalculated Old Vehicle Distributions

$LDV_{old} := SmC_{old} + LMM_{old}$ $\quad LDV_{old} = 0.8$

$LDT_{old} := SUV_{old}$ $\quad LDT_{old} = 0.2$

x100 percent distribution

1992 to 1995 Emissions Data:

By 1992, all vehicles had to conform to the following Federal standard:

$LDV\_9295_{CO} := 3.4 \cdot \frac{gm}{mi}$ $\quad LDV\_9295_{HC} := 0.41 \cdot \frac{gm}{mi}$ $\quad LDV\_9295_{NOx} := 1.0 \cdot \frac{gm}{mi}$

$LDT\_9295_{CO} := 10 \cdot \frac{gm}{mi}$ $\quad LDT\_9295_{HC} := 0.67 \cdot \frac{gm}{mi}$ $\quad LDT\_9295_{NOx} := 1.2 \cdot \frac{gm}{mi}$

1982 - 1991 Emissions Data:

In this time frame, HC were not regulated. Instead Volatile Organic Compounds (VOC) were the standard, and will be considered nearly equivalent to HC's

Vehicles older than 1991 have reached their full usefull life of 10 yrs / 100,000 mi

$LDV\_8291_{CO} := 4.2 \cdot \frac{gm}{mi}$ $\quad LDV\_8291_{VOC} := 0.80 \cdot \frac{gm}{mi}$ $\quad LDV\_8291_{NOx} := 1.0 \frac{gm}{mi}$

$LDT\_8291_{CO} := \frac{10 \cdot 8 + 18}{9} \cdot \frac{gm}{mi}$ $\quad LDT\_8291_{VOC} := 0.80 \cdot \frac{gm}{mi}$ $\quad LDT\_8291_{NOx} := 1.2 \cdot \frac{gm}{mi}$

Pre 1982 Data:

$LDV\_P82_{CO} := \frac{23 \cdot 2 + 39 \cdot 3 + 15 \cdot 5}{10} \cdot \frac{gm}{mi}$ $\quad LDV\_P82_{NOx} := \frac{3 \cdot 3 + 3.1 \cdot 2 + 2 \cdot 4 + 1 \cdot 2}{11} \cdot \frac{gm}{mi}$

$LDV\_P82_{VOC} := \frac{3.4 \cdot 3 + 1.5 \cdot 5 + 0.41 \cdot 2}{10} \cdot \frac{gm}{mi}$

$LDT\_P82_{CO} := \frac{39 \cdot 3 + 20 \cdot 5 + 18 \cdot 4}{12} \cdot \frac{gm}{mi}$ $\quad LDT\_P82_{VOC} := \frac{3.4 \cdot 3 + 2 \cdot 4 + 1.7 \cdot 6}{13} \cdot \frac{gm}{mi}$

$LDT\_P82_{NOx} := \frac{3 \cdot 3 + 3.1 \cdot 4 + 2.3 \cdot 6}{13} \cdot \frac{gm}{mi}$

Emissions Calculations:

1992 - 1995

$LDV9295_{CO} := V_{9295} \cdot (Total\_Worcester\_miles) \cdot LDV\_9295_{CO} \cdot LDC\%$ $LDV9295_{CO} = 0\,gm$

$LDT9295_{CO} := V_{9295} \cdot (Total\_Worcester\_miles) \cdot LDT\_9295_{CO} \cdot LDT\%$ $LDT9295_{CO} = 0\,gm$

$LDV9295_{NOx} := V_{9295} \cdot (Total\_Worcester\_miles) \cdot LDV\_9295_{NOx} \cdot LDC\%$ $LDV9295_{NOx} = 0\,gm$

$LDT9295_{NOx} := V_{9295} \cdot (Total\_Worcester\_miles) \cdot LDT\_9295_{NOx} \cdot LDT\%$ $LDT9295_{NOx} = 0\,gm$

$LDV9295_{HC} := V_{9295} \cdot (Total\_Worcester\_miles) \cdot LDV\_9295_{HC} \cdot LDC\%$ $LDV9295_{HC} = 0\,gm$

$LDT9295_{HC} := V_{9295} \cdot (Total\_Worcester\_miles) \cdot LDT\_9295_{HC} \cdot LDT\%$ $LDT9295_{HC} = 0\,gm$

1982-1991

$LDV8291_{CO} := V_{8291} \cdot (Total\_Worcester\_miles) \cdot LDV\_8291_{CO} \cdot LDC\%$ $LDV8291_{CO} = 0\,gm$

$LDT8291_{CO} := V_{8291} \cdot (Total\_Worcester\_miles) \cdot LDT\_8291_{CO} \cdot LDT\%$ $LDT8291_{CO} = 0\,gm$

$LDV8291_{NOx} := V_{8291} \cdot (Total\_Worcester\_miles) \cdot LDV\_8291_{NOx} \cdot LDC\%$ $LDV8291_{NOx} = 0\,gm$

$LDT8291_{NOx} := V_{8291} \cdot (Total\_Worcester\_miles) \cdot LDT\_8291_{NOx} \cdot LDT\%$ $LDT8291_{NOx} = 0\,gm$

$LDV8291_{VOC} := V_{8291} \cdot (Total\_Worcester\_miles) \cdot LDV\_8291_{VOC} \cdot LDC\%$ $LDV8291_{VOC} = 0\,gm$

$LDT8291_{VOC} := V_{8291} \cdot (Total\_Worcester\_miles) \cdot LDT\_8291_{VOC} \cdot LDT\%$ $LDT8291_{VOC} = 0\,gm$

Pre 1982

$LDVP82_{CO} := V_{P82} \cdot (Total\_Worcester\_miles) \cdot LDV\_P82_{CO} \cdot LDC\%$ $LDVP82_{CO} = 0\,gm$

$LDTP82_{CO} := V_{P82} \cdot (Total\_Worcester\_miles) \cdot LDT\_P82_{CO} \cdot LDT\%$ $LDTP82_{CO} = 0\,gm$

$LDVP82_{NOx} := V_{P82} \cdot (Total\_Worcester\_miles) \cdot LDV\_P82_{NOx} \cdot LDC\%$ $LDVP82_{NOx} = 0\,gm$

$LDTP82_{NOx} := V_{P82} \cdot (Total\_Worcester\_miles) \cdot LDT\_P82_{NOx} \cdot LDT\%$ $LDTP82_{NOx} = 0\,gm$

$LDVP82_{VOC} := V_{P82} \cdot (Total\_Worcester\_miles) \cdot LDV\_P82_{VOC} \cdot LDC\%$ $LDVP82_{VOC} = 0\,gm$

$LDTP82_{VOC} := V_{P82} \cdot (Total\_Worcester\_miles) \cdot LDT\_P82_{VOC} \cdot LDT\%$ $LDTP82_{VOC} = 0\,gm$

Total Emissions of New Vehicles, (English Tons):

Carbon Monoxide:

$$CO_{new} := LMM_{CO} + SmC_{CO} + SUV_{CO}$$

$$CO_{new} = 1409\,ton$$

$LMM_{CO} = 730.4\,ton$

$SmC_{CO} = 332.4\,ton$

$SUV_{CO} = 346.1\,ton$

Nitrous Oxides:

$$NOx_{new} := LMM_{NOx} + SmC_{NOx} + SUV_{NOx}$$

$$NOx_{new} = 114.5\,ton$$

$LMM_{NOx} = 53.1\,ton$

$SmC_{NOx} = 26.4\,ton$

$SUV_{NOx} = 35\,ton$

Hydocarbons:

$$HC_{new} := LMM_{HC} + SmC_{HC} + SUV_{HC}$$

$$HC_{new} = 49.7\,ton$$

$LMM_{HC} = 21.4\,ton$

$SmC_{HC} = 11.2\,ton$

$SUV_{HC} = 17.1\,ton$

Total Emissions:

$$Emissions_{new} := CO_{new} + NOx_{new} + HC_{new}$$

$$Emissions_{new} = 1573.2\,ton$$

Total Emissions of Older Vehicles, (English Tons):

Carbon Monoxide:

$LDV9295_{CO} = 0\,ton$ $LDV8291_{CO} = 0\,ton$ $LDVP82_{CO} = 0\,ton$

$LDT9295_{CO} = 0\,ton$ $LDT8291_{CO} = 0\,ton$ $LDTP82_{CO} = 0\,ton$

$$CO_{old} := LDV9295_{CO} + LDT9295_{CO} + LDV8291_{CO} + LDT8291_{CO} \cdots + LDVP82_{CO} + LDTP82_{CO}$$

Nitrous Oxides:

$LDV9295_{NOx} = 0\,ton$ $LDV8291_{NOx} = 0\,ton$ $LDVP82_{NOx} = 0\,ton$

$LDT9295_{NOx} = 0\,ton$ $LDT8291_{NOx} = 0\,ton$ $LDTP82_{NOx} = 0\,ton$

$$NOx_{old} := LDV9295_{NOx} + LDT9295_{NOx} + LDV8291_{NOx} + LDT8291_{NOx} \cdots + LDVP82_{NOx} + LDTP82_{NOx}$$

HydroCarbons and Volatile Organic Compounds:

$LDV9295_{HC} = 0\,ton$ $LDV8291_{VOC} = 0\,ton$ $LDVP82_{VOC} = 0\,ton$

$LDT9295_{HC} = 0\,ton$ $LDT8291_{VOC} = 0\,ton$ $LDTP82_{VOC} = 0\,ton$

$$HC_{old} := LDV9295_{HC} + LDT9295_{HC} + LDV8291_{VOC} + LDT8291_{VOC} \cdots + LDVP82_{VOC} + LDTP82_{VOC}$$

Totals for Older Vehicles:

$CO_{old} = 0\,ton$ $NOx_{old} = 0\,ton$ $HC_{old} = 0\,ton$

$Emissions_{old} := CO_{old} + NOx_{old} + HC_{old}$

$Emissions_{old} = 0\,ton$

Calculate emissions of a population of SLEV

$Number\_of\_SLEV := (1.0)\cdot\left(V\%_{old}\right)\cdot Worcester\_population\cdot Vehicles\_per\_person$

$Commuter\_miles_{SLEV} := (Travel\_distance)\cdot\left(\frac{2}{day}\right)\cdot(Work\_days)\cdot(Number\_of\_SLEV)$

$Commuter\_miles_{SLEV} = 0.405\,billion\_miles$ driven per year

$Avg\_commuter\_miles_{SLEV} := \frac{Commuter\_miles_{SLE}}{Number\_of\_SLEV}$ $Avg\_commuter\_miles_{SLEV} = 3.654\times10^{3}\,mi$ per vehicle driven per year

$Weekend\_miles_{SLEV} := \left(\frac{Travel\_distance}{2}\right)\cdot\left(\frac{2}{day}\right)\cdot(Week\_ends)\cdot(Number\_of\_SLEV)$

$Weekend\_miles_{SLEV} = 80.629\,million\_miles$ driven per year

$Avg\_weekend\_miles_{SLEV} := \frac{Weekend\_miles_{SLEV}}{Number\_of\_SLEV}$ $Avg\_weekend\_miles_{SLEV} = 728\,mi$ per venicle driven per year

$Total\_Worcester\_miles_{SLEV} := Weekend\_miles_{SLEV} + Commuter\_miles_{SLEV}$

$Total\_Worcester\_miles_{SLEV} = 0.485\,billion\_miles$ driven per year

$SLEV_{CO} := Total\_Worcester\_miles_{SLEV}\cdot SLEV\_CO$ $SLEV_{CO} = 534.978\,ton$

$SLEV_{HC} := Total\_Worcester\_miles_{SLEV}\cdot SLEV\_HC$ $SLEV_{HC} = 5.35\,ton$

$SLEV_{NOx} := Total\_Worcester\_miles_{SLEV}\cdot SLEV\_NOx$ $SLEV_{NOx} = 10.7\,ton$

$Total\_Emissions := Emissions_{new} + Emissions_{old} + SLEV_{CO} + SLEV_{HC} + SLEV_{NOx}$

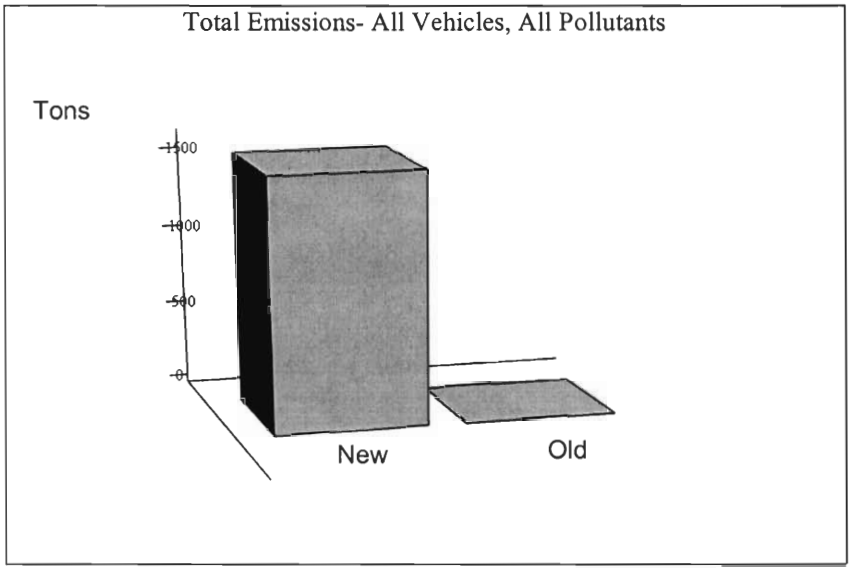
$Total\_Emissions = 2124.2\,ton$

$CO_{Tot} := SLEV_{CO} + CO_{old} + CO_{new}$ $\quad CO_{Tot} = 1944\,ton$

$NOx_{Tot} := SLEV_{NOx} + NOx_{old} + NOx_{new}$ $\quad NOx_{Tot} = 125.2\,ton$

$HC_{Tot} := SLEV_{HC} + HC_{old} + HC_{new}$ $\quad HC_{Tot} = 55.1\,ton$

$$Graph1 := \left(\frac{Emissions_{new}}{2000} \quad \frac{Emissions_{old}}{2000} \right)$$



Replacing 100% of all Small Cars w/Hybrids

billion_miles := $10^9 \cdot mi$

million_miles := $10^6 \cdot mi$

Assumptions:

Vehicles traveling through Worcester Travel an average of 7 miles each

Travel_distance := $7 \cdot mi$

40% of the pollutants in the air come from vehicles

Work_days := $261 \cdot day$

Week_ends := $104 \cdot day$

City Data:

Worcester_population := 254900 people

Vehicles_per_person := 0.79

Percentages of Vehicle Types:

%NotReplaced := 0.0 %Hybrid := 1.0

Newer Vehicles:

SUV := 0.275 SmC := 0.21 LMM := 0.51

Older Vehicles:

SUV_{old} := 0.20 SmC_{old} := 0.20 LMM_{old} := 0.60

Age distribution of Vehicles on the Roads:

1996 - 2002 V_{9602} := 0.45

1992 - 1995 V_{9295} := 0.30

1982 - 1991 V_{8291} := 0.22

Pre 1982 V_{P82} := 0.03

Transitional Low Emissions Vehicle Data:

TLEV_NMOG := $0.125 \cdot \frac{gm}{mi}$ TLEV_NOx := $0.4 \cdot \frac{gm}{mi}$

TLEV_CO := $3.4 \cdot \frac{gm}{mi}$ TLEV_HCHO := $0.015 \cdot \frac{gm}{mi}$

TLEV HC := TLEV NMOG + TLEV_HCHO

TLEV_HC = $0.14 \frac{gm}{mi}$

Low Emissions Vehicle Data:

LEV_NMOG := $0.075 \cdot \frac{gm}{mi}$ LEV_NOx := $0.2 \cdot \frac{gm}{mi}$

LEV_CO := $3.4 \cdot \frac{gm}{mi}$ LEV_HCHO := $0.015 \cdot \frac{gm}{mi}$

LEV_HC := LEV_NMOG + LEV_HCHO

LEV_HC = $0.09 \frac{gm}{mi}$

Ultra Low Emissions Vehicle Data:

$$ULEV\_NMOG := 0.04 \cdot \frac{gm}{mi} \qquad ULEV\_NOx := 0.2 \cdot \frac{gm}{mi}$$

$$ULEV\_CO := 1.7 \cdot \frac{gm}{mi} \qquad ULEV\_HCHO := 0.008 \cdot \frac{gm}{mi}$$

$$ULEV\_HC := ULEV\_NMOG + ULEV\_HCHO$$

$$ULEV\_HC = 0.048 \frac{gm}{mi}$$

Super Low Emissions Vehicle Data:

$$SLEV\_CO := 1.0 \cdot \frac{gm}{mi} \qquad SLEV\_HC := 0.01 \cdot \frac{gm}{mi} \qquad SLEV\_NOx := 0.02 \cdot \frac{gm}{mi}$$

Zero Emissions Vehicle Data:

$$ZEV\_CO := 0 \cdot \frac{gm}{mi} \qquad ZEV\_HC := 0 \cdot \frac{gm}{mi} \qquad ZEV\_NOx := 0 \cdot \frac{gm}{mi}$$

Tier 1 Emissions Data:

$$T1\_CO := 4.2 \cdot \frac{gm}{mi} \qquad T1\_HC := 0.31 \cdot \frac{gm}{mi} \qquad T1\_NOx := 0.6 \cdot \frac{gm}{mi}$$

Tabulated Vehicle Distribution for New Vehicles:

$$SUV\_ZEV\_percentage := \frac{0.21}{100} \qquad LMM\_ZEV\_percentage := 0$$

$$SUV\_SLEV\_percentage := \frac{0.86}{100} \qquad LMM\_SLEV\_percentage := \frac{0.36}{100}$$

$$SUV\_ULEV\_percentage := \frac{4.5}{100} \qquad LMM\_ULEV\_percentage := \frac{19.13}{100}$$

$$SUV\_LEV\_percentage := \frac{51.82}{100} \qquad LMM\_LEV\_percentage := \frac{70.40}{100}$$

$$SUV\_TLEV\_percentage := \frac{1.5}{100} \qquad LMM\_TLEV\_percentage := \frac{7.94}{100}$$

$$SUV\_T1\_percentage := \frac{41.11}{100} \qquad LMM\_T1\_percentage := \frac{2.17}{100}$$

$$SmC\_ZEV\_percentage := \frac{0.26}{100} \qquad SmC\_LEV\_percentage := \frac{65.17}{100}$$

$$SmC\_SLEV\_percentage := \frac{1.06}{100} \qquad SmC\_TLEV\_percentage := \frac{9.5}{100}$$

$$SmC\_ULEV\_percentage := \frac{15.04}{100} \qquad SmC\_T1\_percentage := \frac{8.97}{100}$$

Percentages of Each New Vehicle Type Observed on the Road:

SUV_on_road := .2187 LMM_on_road := .5418

SmC_on_road := .2395·%NotReplaced SmC_{Hybrid} := 0.2187·%Hybrid

Equations:

Number_of_Vehicles := Worcester_population·Vehicles_per_person

Number_of_Vehicles = 2.014×10^5

$$\text{Commuter\_miles} := (\text{Travel\_distance})\cdot\left(\frac{2}{\text{day}}\right)\cdot(\text{Work\_days})\cdot(\text{Number\_of\_Vehicles})$$

Commuter_miles = 0.736 billion_miles driven per year

$$\text{Avg\_commuter\_miles} := \frac{\text{Commuter\_miles}}{\text{Number\_of\_Vehicles}} \qquad \text{Avg\_commuter\_miles} = 3.654 \times 10^3 \text{ mi per vehicle driven per year}$$

$$\text{Weekend\_miles} := \left(\frac{\text{Travel\_distance}}{2}\right)\cdot\left(\frac{2}{\text{day}}\right)\cdot(\text{Week\_ends})\cdot(\text{Number\_of\_Vehicles})$$

Weekend_miles = 146.598 million_milesriven per year

$$\text{Avg\_weekend\_miles} := \frac{\text{Weekend\_miles}}{\text{Number\_of\_Vehicles}} \qquad \text{Avg\_weekend\_miles} = 728 \text{ mi per vehicle driven per year}$$

Total_Worcester_miles := Weekend_miles + Commuter_miles Total_Worcester_miles = 0.882 billion_miles driven per year

Emissions Due to New SUV's

$$\text{SUV}_{NOx} := V_{9602}\cdot\left[\begin{array}{l}(\text{Total\_Worcester\_miles})\cdot(\text{SUV\_on\_road})\cdot(\text{SUV\_ZEV\_percentage})\cdot(\text{ZEV\_NOx}) \ldots \\ +(\text{Total\_Worcester\_miles})\cdot(\text{SUV\_on\_road})\cdot(\text{SUV\_SLEV\_percentage})\cdot(\text{SLEV\_NOx}) \ldots \\ +(\text{Total\_Worcester\_miles})\cdot(\text{SUV\_on\_road})\cdot(\text{SUV\_T1\_percentage})\cdot(\text{T1\_NOx}) \ldots \\ +(\text{Total\_Worcester\_miles})\cdot(\text{SUV\_on\_road})\cdot(\text{SUV\_TLEV\_percentage})\cdot(\text{TLEV\_NOx}) \ldots \\ +(\text{Total\_Worcester\_miles})\cdot(\text{SUV\_on\_road})\cdot(\text{SUV\_LEV\_percentage})\cdot(\text{LEV\_NOx}) \ldots \\ +[(\text{Total\_Worcester\_miles})\cdot(\text{SUV\_on\_road})\cdot(\text{SUV\_ULEV\_percentage})\cdot(\text{ULEV\_NOx})]\end{array}\right]$$

$$\text{SUV}_{NOx} = 3.174 \times 10^7 \text{ gm}$$

$$\text{SUV}_{HC} := V_{9602}\cdot\left[\begin{array}{l}(\text{Total\_Worcester\_miles})\cdot(\text{SUV\_on\_road})\cdot(\text{SUV\_ZEV\_percentage})\cdot(\text{ZEV\_HC}) \ldots \\ +(\text{Total\_Worcester\_miles})\cdot(\text{SUV\_on\_road})\cdot(\text{SUV\_SLEV\_percentage})\cdot(\text{SLEV\_HC}) \ldots \\ +(\text{Total\_Worcester\_miles})\cdot(\text{SUV\_on\_road})\cdot(\text{SUV\_T1\_percentage})\cdot(\text{T1\_HC}) \ldots \\ +(\text{Total\_Worcester\_miles})\cdot(\text{SUV\_on\_road})\cdot(\text{SUV\_TLEV\_percentage})\cdot(\text{TLEV\_HC}) \ldots \\ +(\text{Total\_Worcester\_miles})\cdot(\text{SUV\_on\_road})\cdot(\text{SUV\_LEV\_percentage})\cdot(\text{LEV\_HC}) \ldots \\ +[(\text{Total\_Worcester\_miles})\cdot(\text{SUV\_on\_road})\cdot(\text{SUV\_ULEV\_percentage})\cdot(\text{ULEV\_HC})]\end{array}\right]$$

$$\text{SUV}_{HC} = 1.549 \times 10^7 \text{ gm}$$

$$SUV_{CO} := V_{9602}\cdot\Big[\begin{array}{l}(Total\_Worcester\_miles)\cdot(SUV\_on\_road)\cdot(SUV\_ZEV\_percentage)\cdot(ZEV\_CO)\ ...\\ +(Total\_Worcester\_miles)\cdot(SUV\_on\_road)\cdot(SUV\_SLEV\_percentage)\cdot(SLEV\_CO)\ ...\\ +(Total\_Worcester\_miles)\cdot(SUV\_on\_road)\cdot(SUV\_T1\_percentage)\cdot(T1\_CO)\ ...\\ +(Total\_Worcester\_miles)\cdot(SUV\_on\_road)\cdot(SUV\_TLEV\_percentage)\cdot(TLEV\_CO)\ ...\\ +(Total\_Worcester\_miles)\cdot(SUV\_on\_road)\cdot(SUV\_LEV\_percentage)\cdot(LEV\_CO)\ ...\\ +[(Total\_Worcester\_miles)\cdot(SUV\_on\_road)\cdot(SUV\_ULEV\_percentage)\cdot(ULEV\_CO)]\end{array}\Big]$$

$$SUV_{CO} = 3.148\times 10^{8}\,gm$$

Emissions Due to New Small Cars

$$SmC_{NOx} := V_{9602}\cdot\Big[\begin{array}{l}(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_ZEV\_percentage)\cdot(ZEV\_NOx)\ ...\\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_SLEV\_percentage)\cdot(SLEV\_NOx)\ ...\\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_T1\_percentage)\cdot(T1\_NOx)\ ...\\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_TLEV\_percentage)\cdot(TLEV\_NOx)\ ...\\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_LEV\_percentage)\cdot(LEV\_NOx)\ ...\\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_ULEV\_percentage)\cdot(ULEV\_NOx)\ ...\\ +(Total\_Worcester\_miles)\cdot\left(SmC_{Hybrid}\right)\cdot(SLEV\_NOx)\end{array}\Big]$$

$$SmC_{NOx} = 1.737\times 10^{6}\,gm$$

$$SmC_{HC} := V_{9602}\cdot\Big[\begin{array}{l}(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_ZEV\_percentage)\cdot(ZEV\_HC)\ ...\\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_SLEV\_percentage)\cdot(SLEV\_HC)\ ...\\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_T1\_percentage)\cdot(T1\_HC)\ ...\\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_TLEV\_percentage)\cdot(TLEV\_HC)\ ...\\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_LEV\_percentage)\cdot(LEV\_HC)\ ...\\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_ULEV\_percentage)\cdot(ULEV\_HC)\ ...\\ +(Total\_Worcester\_miles)\cdot\left(SmC_{Hybrid}\right)\cdot(SLEV\_HC)\end{array}\Big]$$

$$SmC_{HC} = 8.684\times 10^{5}\,gm$$

$$SmC_{CO} := V_{9602}\cdot\Big[\begin{array}{l}(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_ZEV\_percentage)\cdot(ZEV\_CO)\ ...\\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_SLEV\_percentage)\cdot(SLEV\_CO)\ ...\\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_T1\_percentage)\cdot(T1\_CO)\ ...\\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_TLEV\_percentage)\cdot(TLEV\_CO)\ ...\\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_LEV\_percentage)\cdot(LEV\_CO)\ ...\\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_ULEV\_percentage)\cdot(ULEV\_CO)\ ...\\ +(Total\_Worcester\_miles)\cdot\left(SmC_{Hybrid}\right)\cdot(SLEV\_CO)\end{array}\Big]$$

$$SmC_{CO} = 8.684\times 10^{7}\,gm$$

Emissions Due to New Large-Medium cars and Minivans

$$LMM_{NOx} := V_{9602}\cdot\left[\begin{array}{l}(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_ZEV\_percentage)\cdot(ZEV\_NOx)\ ... \\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_SLEV\_percentage)\cdot(SLEV\_NOx)\ ... \\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_T1\_percentage)\cdot(T1\_NOx)\ ... \\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_TLEV\_percentage)\cdot(TLEV\_NOx)\ ... \\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_LEV\_percentage)\cdot(LEV\_NOx)\ ... \\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_ULEV\_percentage)\cdot(ULEV\_NOx)\end{array}\right]$$

$$LMM_{NOx} = 4.817\times 10^{7}\ gm$$

$$LMM_{HC} := V_{9602}\cdot\left[\begin{array}{l}(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_ZEV\_percentage)\cdot(ZEV\_HC)\ ... \\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_SLEV\_percentage)\cdot(SLEV\_HC)\ ... \\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_T1\_percentage)\cdot(T1\_HC)\ ... \\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_TLEV\_percentage)\cdot(TLEV\_HC)\ ... \\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_LEV\_percentage)\cdot(LEV\_HC)\ ... \\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_ULEV\_percentage)\cdot(ULEV\_HC)\end{array}\right]$$

$$LMM_{HC} = 1.945\times 10^{7}\ gm$$

$$LMM_{CO} := V_{9602}\cdot\left[\begin{array}{l}(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_ZEV\_percentage)\cdot(ZEV\_CO)\ ... \\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_SLEV\_percentage)\cdot(SLEV\_CO)\ ... \\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_T1\_percentage)\cdot(T1\_CO)\ ... \\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_TLEV\_percentage)\cdot(TLEV\_CO)\ ... \\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_LEV\_percentage)\cdot(LEV\_CO)\ ... \\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_ULEV\_percentage)\cdot(ULEV\_CO)\end{array}\right]$$

$$LMM_{CO} = 6.634\times 10^{8}\ gm$$

Emissions Due to Vehicles manufactured 1995 or before:

Note: Prior to 1996 vehicles were generally classified as either Light Duty Vehicles (LDV) or Light Dut Trucks (LDT)

Recalculated Old Vehicle Distributions

$LDT\% := SUV_{old}$ $LDT\% = 0.2$

$LDC\% := SmC_{old} \cdot \%NotReplaced + LMM_{old}$ $LDC\% = 0.6$ x100 percent distribution

$LDV_{Hybrid} := SmC_{old} \cdot \%Hybrid$

1992 to 1995 Emissions Data:

By 1992, all vehicles had to conform to the following Federal standard:

$LDV\_9295_{CO} := 3.4 \cdot \frac{gm}{mi}$ $LDV\_9295_{HC} := 0.41 \cdot \frac{gm}{mi}$ $LDV\_9295_{NOx} := 1.0 \cdot \frac{gm}{mi}$

$LDT\_9295_{CO} := 10 \cdot \frac{gm}{mi}$ $LDT\_9295_{HC} := 0.67 \cdot \frac{gm}{mi}$ $LDT\_9295_{NOx} := 1.2 \cdot \frac{gm}{mi}$

1982 - 1991 Emissions Data:

In this time frame, HC were not regulated. Instead Volatile Organic Compounds (VOC) were the standard, and will be considered nearly equivalent to HC's

Vehicles older than 1991 have reached their full usefull life of 10 yrs / 100,000 mi

$LDV\_8291_{CO} := 4.2 \cdot \frac{gm}{mi}$ $LDV\_8291_{VOC} := 0.80 \cdot \frac{gm}{mi}$ $LDV\_8291_{NOx} := 1.0 \frac{gm}{mi}$

$LDT\_8291_{CO} := \frac{10 \cdot 8 + 18}{9} \cdot \frac{gm}{mi}$ $LDT\_8291_{VOC} := 0.80 \cdot \frac{gm}{mi}$ $LDT\_8291_{NOx} := 1.2 \cdot \frac{gm}{mi}$

Pre 1982 Data:

$LDV\_P82_{CO} := \frac{23 \cdot 2 + 39 \cdot 3 + 15 \cdot 5}{10} \cdot \frac{gm}{mi}$ $LDV\_P82_{NOx} := \frac{3 \cdot 3 + 3.1 \cdot 2 + 2 \cdot 4 + 1 \cdot 2}{11} \cdot \frac{gm}{mi}$

$LDV\_P82_{VOC} := \frac{3.4 \cdot 3 + 1.5 \cdot 5 + 0.41 \cdot 2}{10} \cdot \frac{gm}{mi}$

$LDT\_P82_{CO} := \frac{39 \cdot 3 + 20 \cdot 5 + 18 \cdot 4}{12} \cdot \frac{gm}{mi}$ $LDT\_P82_{VOC} := \frac{3.4 \cdot 3 + 2 \cdot 4 + 1.7 \cdot 6}{13} \cdot \frac{gm}{mi}$

$LDT\_P82_{NOx} := \frac{3 \cdot 3 + 3.1 \cdot 4 + 2.3 \cdot 6}{13} \cdot \frac{gm}{mi}$

Emissions Calculations:

1992 - 1995

$$LDV9295_{CO} := \left[V_{9295}\cdot(Total\_Worcester\_miles)\cdot LDV\_9295_{CO}\cdot LDC\%\right] \ldots + V_{9295}\cdot(Total\_Worcester\_miles)\cdot SLEV\_CO\cdot LDV_{Hybrid} \quad LDV9295_{CO} = 5.93\times 10^{8}\,gm$$

$$LDT9295_{CO} := V_{9295}\cdot(Total\_Worcester\_miles)\cdot LDT\_9295_{CO}\cdot LDT\% \quad LDT9295_{CO} = 5.294\times 10^{8}\,gm$$

$$LDV9295_{NOx} := V_{9295}\cdot(Total\_Worcester\_miles)\cdot LDV\_9295_{NOx}\cdot LDC\% + V_{9295}\cdot(Total\_Worcester\_miles)\cdot SLEV\_NOx\cdot LDV_{Hybrid} \quad LDV9295_{NOx} = 1.599\times 10^{8}\,gm$$

$$LDT9295_{NOx} := V_{9295}\cdot(Total\_Worcester\_miles)\cdot LDT\_9295_{NOx}\cdot LDT\% \quad LDT9295_{NOx} = 6.353\times 10^{7}\,gm$$

$$LDV9295_{HC} := V_{9295}\cdot(Total\_Worcester\_miles)\cdot LDV\_9295_{HC}\cdot LDC\% \ldots + V_{9295}\cdot(Total\_Worcester\_miles)\cdot SLEV\_HC\cdot LDV_{Hybrid} \quad LDV9295_{HC} = 6.565\times 10^{7}\,gm$$

$$LDT9295_{HC} := V_{9295}\cdot(Total\_Worcester\_miles)\cdot LDT\_9295_{HC}\cdot LDT\% \quad LDT9295_{HC} = 3.547\times 10^{7}\,gm$$

1982-1991

$$LDV8291_{CO} := V_{8291}\cdot(Total\_Worcester\_miles)\cdot LDV\_8291_{CO}\cdot LDC\% \ldots + V_{8291}\cdot(Total\_Worcester\_miles)\cdot SLEV\_CO\cdot LDV_{Hybrid} \quad LDV8291_{CO} = 5.28\times 10^{8}\,gm$$

$$LDT8291_{CO} := V_{8291}\cdot(Total\_Worcester\_miles)\cdot LDT\_8291_{CO}\cdot LDT\% \quad LDT8291_{CO} = 4.228\times 10^{8}\,gm$$

$$LDV8291_{NOx} := V_{8291}\cdot(Total\_Worcester\_miles)\cdot LDV\_8291_{NOx}\cdot LDC\% + V_{8291}\cdot(Total\_Worcester\_miles)\cdot SLEV\_NOx\cdot LDV_{Hybrid} \quad LDV8291_{NOx} = 1.173\times 10^{8}\,gm$$

$$LDT8291_{NOx} := V_{8291}\cdot(Total\_Worcester\_miles)\cdot LDT\_8291_{NOx}\cdot LDT\% \quad LDT8291_{NOx} = 4.659\times 10^{7}\,gm$$

$$LDV8291_{VOC} := V_{8291}\cdot(Total\_Worcester\_miles)\cdot LDV\_8291_{VOC}\cdot LDC\% + V_{8291}\cdot(Total\_Worcester\_miles)\cdot SLEV\_HC\cdot LDV_{Hybrid} \quad LDV8291_{VOC} = 9.357\times 10^{7}\,gm$$

$$LDT8291_{VOC} := V_{8291}\cdot(Total\_Worcester\_miles)\cdot LDT\_8291_{VOC}\cdot LDT\% \quad LDT8291_{VOC} = 3.106\times 10^{7}\,gm$$

Pre 1982

$$LDVP82_{CO} := V_{P82}\cdot(Total\_Worcester\_miles)\cdot LDV\_P82_{CO}\cdot LDC\% \ldots + V_{P82}\cdot(Total\_Worcester\_miles)\cdot SLEV\_CO\cdot LDV_{Hybrid} \quad LDVP82_{CO} = 3.833\times 10^{8}\,gm$$

$$LDTP82_{CO} := V_{P82}\cdot(Total\_Worcester\_miles)\cdot LDT\_P82_{CO}\cdot LDT\% \quad LDTP82_{CO} = 1.275\times 10^{8}\,gm$$

$$LDVP82_{NOx} := V_{P82}\cdot(Total\_Worcester\_miles)\cdot LDV\_P82_{NOx}\cdot LDC\% \ldots + V_{P82}\cdot(Total\_Worcester\_miles)\cdot SLEV\_NOx\cdot LDV_{Hybrid} \quad LDVP82_{NOx} = 3.649\times 10^{7}\,gm$$

$$LDTP82_{NOx} := V_{P82}\cdot(Total\_Worcester\_miles)\cdot LDT\_P82_{NOx}\cdot LDT\% \quad LDTP82_{NOx} = 1.434\times 10^{7}\,gm$$

$$LDVP82_{VOC} := V_{P82}\cdot(Total\_Worcester\_miles)\cdot LDV\_P82_{VOC}\cdot LDC\% \ldots + V_{P82}\cdot(Total\_Worcester\_miles)\cdot SLEV\_HC\cdot LDV_{Hybrid} \quad LDVP82_{VOC} = 2.947\times 10^{7}\,gm$$

$$LDTP82_{VOC} := V_{P82}\cdot(Total\_Worcester\_miles)\cdot LDT\_P82_{VOC}\cdot LDT\% \quad LDTP82_{VOC} = 1.157\times 10^{7}\,gm$$

Total Emissions of New Vehicles, (English Tons):

Carbon Monoxide:

$$CO_{new} := LMM_{CO} + SmC_{CO} + SUV_{CO} \qquad CO_{new} = 1174\,ton$$

$LMM_{CO} = 731.3\,ton$

$SmC_{CO} = 95.7\,ton$

$SUV_{CO} = 347\,ton$

Nitrous Oxides:

$$NOx_{new} := LMM_{NOx} + SmC_{NOx} + SUV_{NOx} \qquad NOx_{new} = 90\,ton$$

$LMM_{NOx} = 53.1\,ton$

$SmC_{NOx} = 1.9\,ton$

$SUV_{NOx} = 35\,ton$

Hydocarbons:

$$HC_{new} := LMM_{HC} + SmC_{HC} + SUV_{HC} \qquad HC_{new} = 39.5\,ton$$

$LMM_{HC} = 21.4\,ton$

$SmC_{HC} = 1\,ton$

$SUV_{HC} = 17.1\,ton$

Total Emissions:

$$Emissions_{new} := CO_{new} + NOx_{new} + HC_{new} \qquad Emissions_{new} = 1303.4\,ton$$

Total Emissions of Older Vehicles, (English Tons):

Carbon Monoxide:

$LDV9295_{CO} = 653.6\,ton$ $\quad LDV8291_{CO} = 582.1\,ton$ $\quad LDVP82_{CO} = 422.5\,ton$

$LDT9295_{CO} = 583.6\,ton$ $\quad LDT8291_{CO} = 466\,ton$ $\quad LDTP82_{CO} = 140.6\,ton$

$$CO_{old} := LDV9295_{CO} + LDT9295_{CO} + LDV8291_{CO} + LDT8291_{CO} \ldots + LDVP82_{CO} + LDTP82_{CO} \qquad CO_{old} = 2848.4\,ton$$

Nitrous Oxides:

$LDV9295_{NOx} = 176.3\,ton$ $\quad LDV8291_{NOx} = 129.3\,ton$ $\quad LDVP82_{NOx} = 40.2\,ton$

$LDT9295_{NOx} = 70\,ton$ $\quad LDT8291_{NOx} = 51.4\,ton$ $\quad LDTP82_{NOx} = 15.8\,ton$

$$NOx_{old} := LDV9295_{NOx} + LDT9295_{NOx} + LDV8291_{NOx} + LDT8291_{NOx} \ldots + LDVP82_{NOx} + LDTP82_{NOx} \qquad NOx_{old} = 482.9\,ton$$

HydroCarbons and Volatile Organic Compounds:

$LDV9295_{HC} = 72.4\,ton$ $LDV8291_{VOC} = 103.1\,ton$ $LDVP82_{VOC} = 32.5\,ton$

$LDT9295_{HC} = 39.1\,ton$ $LDT8291_{VOC} = 34.2\,ton$ $LDTP82_{VOC} = 12.7\,ton$

$$HC_{old} := LDV9295_{HC} + LDT9295_{HC} + LDV8291_{VOC} + LDT8291_{VOC} \cdots + LDVP82_{VOC} + LDTP82_{VOC}$$

$HC_{old} = 294.1\,ton$

Totals for Older Vehicles:

$CO_{old} = 2848.4\,ton$ $NOx_{old} = 482.9\,ton$ $HC_{old} = 294.1\,ton$

$Emissions_{old} := CO_{old} + NOx_{old} + HC_{old}$

$Emissions_{old} = 3625.4\,ton$

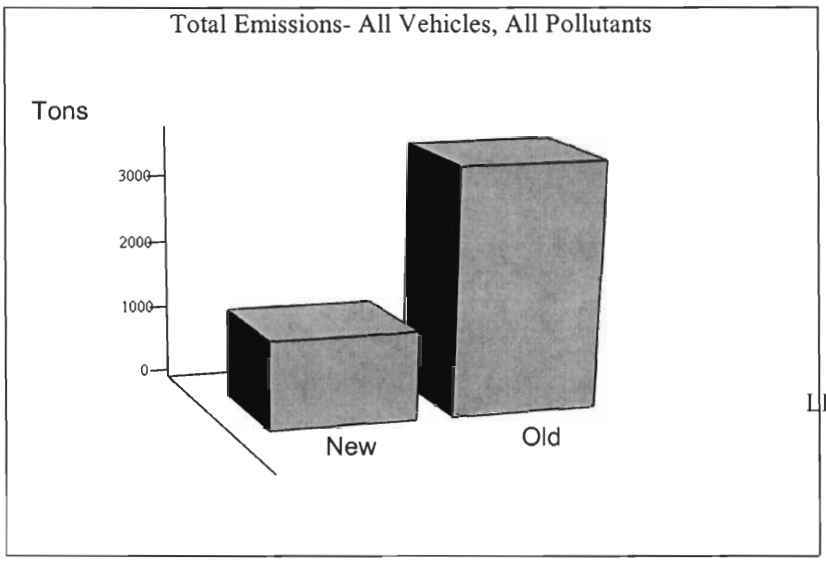
$T := Emissions_{new} + Emissions_{old}$ $T = 4928.9\,ton$

$CO_{Tot} := CO_{new} + CO_{old}$ $CO_{Tot} = 4022.4\,ton$

$NOx_{Tot} := NOx_{new} + NOx_{old}$ $NOx_{Tot} = 572.924\,ton$

$HC_{Tot} := HC_{old} + HC_{new}$ $HC_{Tot} = 333.567\,ton$

$$Graph1 := \left(\frac{Emissions_{new}}{2000} \quad \frac{Emissions_{old}}{2000} \right)$$



$LDTP82_{VOC} = 12.7\,ton$

Replacing 25% of all LDT's w/Hybrids

billion_miles := $10^9 \cdot mi$

million_miles := $10^6 \cdot mi$

Assumptions:

Vehicles traveling through Worcester Travel an average of 7 miles each

Travel_distance := $7 \cdot mi$

40% of the pollutants in the air come from vehicles

Work_days := $261 \cdot day$

Week_ends := $104 \cdot day$

City Data:

Worcester_population := 254900 people

Vehicles_per_person := 0.79

Percentages of Vehicle Types:

%NotReplaced := 0.75 %Hybrid := 0.25

Newer Vehicles:

SUV := 0.275 SmC := 0.21 LMM := 0.51

Older Vehicles:

SUV_{old} := 0.20 SmC_{old} := 0.20 LMM_{old} := 0.60

Age distribution of Vehicles on the Roads:

1996 - 2002 V_{9602} := 0.45

1992 - 1995 V_{9295} := 0.30

1982 - 1991 V_{8291} := 0.22

Pre 1982 V_{P82} := 0.03

Transitional Low Emissions Vehicle Data:

TLEV_NMOG := $0.125 \cdot \frac{gm}{mi}$ TLEV_NOx := $0.4 \cdot \frac{gm}{mi}$

TLEV_CO := $3.4 \cdot \frac{gm}{mi}$ TLEV_HCHO := $0.015 \cdot \frac{gm}{mi}$

TLEV HC := TLEV NMOG + TLEV_HCHO

TLEV_HC = $0.14 \frac{gm}{mi}$

Low Emissions Vehicle Data:

LEV_NMOG := $0.075 \cdot \frac{gm}{mi}$ LEV_NOx := $0.2 \cdot \frac{gm}{mi}$

LEV_CO := $3.4 \cdot \frac{gm}{mi}$ LEV_HCHO := $0.015 \cdot \frac{gm}{mi}$

LEV_HC := LEV_NMOG + LEV_HCHO

LEV_HC = $0.09 \frac{gm}{mi}$

Ultra Low Emissions Vehicle Data:

$$ULEV\_NMOG := 0.04 \cdot \frac{gm}{mi} \qquad ULEV\_NOx := 0.2 \cdot \frac{gm}{mi}$$

$$ULEV\_CO := 1.7 \cdot \frac{gm}{mi} \qquad ULEV\_HCHO := 0.008 \cdot \frac{gm}{mi}$$

$$ULEV\_HC := ULEV\_NMOG + ULEV\_HCHO$$

$$ULEV\_HC = 0.048 \frac{gm}{mi}$$

Super Low Emissions Vehicle Data:

$$SLEV\_CO := 1.0 \cdot \frac{gm}{mi} \qquad SLEV\_HC := 0.01 \cdot \frac{gm}{mi} \qquad SLEV\_NOx := 0.02 \cdot \frac{gm}{mi}$$

Zero Emissions Vehicle Data:

$$ZEV\_CO := 0 \cdot \frac{gm}{mi} \qquad ZEV\_HC := 0 \cdot \frac{gm}{mi} \qquad ZEV\_NOx := 0 \cdot \frac{gm}{mi}$$

Tier 1 Emissions Data:

$$T1\_CO := 4.2 \cdot \frac{gm}{mi} \qquad T1\_HC := 0.31 \cdot \frac{gm}{mi} \qquad T1\_NOx := 0.6 \cdot \frac{gm}{mi}$$

Tabulated Vehicle Distribution for New Vehicles:

$$SUV\_ZEV\_percentage := \frac{0.21}{100} \qquad LMM\_ZEV\_percentage := 0$$

$$SUV\_SLEV\_percentage := \frac{0.86}{100} \qquad LMM\_SLEV\_percentage := \frac{0.36}{100}$$

$$SUV\_ULEV\_percentage := \frac{4.5}{100} \qquad LMM\_ULEV\_percentage := \frac{19.13}{100}$$

$$SUV\_LEV\_percentage := \frac{51.82}{100} \qquad LMM\_LEV\_percentage := \frac{70.40}{100}$$

$$SUV\_TLEV\_percentage := \frac{1.5}{100} \qquad LMM\_TLEV\_percentage := \frac{7.94}{100}$$

$$SUV\_T1\_percentage := \frac{41.11}{100} \qquad LMM\_T1\_percentage := \frac{2.17}{100}$$

$$SmC\_ZEV\_percentage := \frac{0.26}{100} \qquad SmC\_LEV\_percentage := \frac{65.17}{100}$$

$$SmC\_SLEV\_percentage := \frac{1.06}{100} \qquad SmC\_TLEV\_percentage := \frac{9.5}{100}$$

$$SmC\_ULEV\_percentage := \frac{15.04}{100} \qquad SmC\_T1\_percentage := \frac{8.97}{100}$$

Percentages of Each New Vehicle Type Observed on the Road:

SmC_on_road := .2395 LMM_on_road := .5418

SUV_on_road := .2187·%NotReplaced SUV_{Hybrid} := 0.2187·%Hybrid

Equations:

Number_of_Vehicles := Worcester_population·Vehicles_per_person

$$\text{Number\_of\_Vehicles} = 2.014 \times 10^5$$

$$\text{Commuter\_miles} := (\text{Travel\_distance})\cdot\left(\frac{2}{\text{day}}\right)\cdot(\text{Work\_days})\cdot(\text{Number\_of\_Vehicles})$$

Commuter_miles = 0.736 billion_miles driven per year

$$\text{Avg\_commuter\_miles} := \frac{\text{Commuter\_miles}}{\text{Number\_of\_Vehicles}} \qquad \text{Avg\_commuter\_miles} = 3.654 \times 10^3 \text{ mi per vehicle driven per year}$$

$$\text{Weekend\_miles} := \left(\frac{\text{Travel\_distance}}{2}\right)\cdot\left(\frac{2}{\text{day}}\right)\cdot(\text{Week\_ends})\cdot(\text{Number\_of\_Vehicles})$$

Weekend_miles = 146.598 million_milesriven per year

$$\text{Avg\_weekend\_miles} := \frac{\text{Weekend\_miles}}{\text{Number\_of\_Vehicles}} \qquad \text{Avg\_weekend\_miles} = 728 \text{ mi per vehicle driven per year}$$

Total_Worcester_miles := Weekend_miles + Commuter_miles Total_Worcester_miles = 0.882 billion_miles driven per year

Emissions Due to New SUV's

$$SUV_{NOx} := V_{9602}\cdot\left[\begin{array}{l}(\text{Total\_Worcester\_miles})\cdot(\text{SUV\_on\_road})\cdot(\text{SUV\_ZEV\_percentage})\cdot(\text{ZEV\_NOx}) \ldots \\ +(\text{Total\_Worcester\_miles})\cdot(\text{SUV\_on\_road})\cdot(\text{SUV\_SLEV\_percentage})\cdot(\text{SLEV\_NOx}) \ldots \\ +(\text{Total\_Worcester\_miles})\cdot(\text{SUV\_on\_road})\cdot(\text{SUV\_T1\_percentage})\cdot(\text{T1\_NOx}) \ldots \\ +(\text{Total\_Worcester\_miles})\cdot(\text{SUV\_on\_road})\cdot(\text{SUV\_TLEV\_percentage})\cdot(\text{TLEV\_NOx}) \ldots \\ +(\text{Total\_Worcester\_miles})\cdot(\text{SUV\_on\_road})\cdot(\text{SUV\_LEV\_percentage})\cdot(\text{LEV\_NOx}) \ldots \\ +[(\text{Total\_Worcester\_miles})\cdot(\text{SUV\_on\_road})\cdot(\text{SUV\_ULEV\_percentage})\cdot(\text{ULEV\_NOx})] \ldots \\ +(\text{Total\_Worcester\_miles})\cdot\left(SUV_{Hybrid}\right)\cdot(\text{SLEV\_NOx})\end{array}\right]$$

$$SUV_{NOx} = 2.424 \times 10^7 \text{ gm}$$

$$SUV_{HC} := V_{9602}\cdot\left[\begin{array}{l}(\text{Total\_Worcester\_miles})\cdot(\text{SUV\_on\_road})\cdot(\text{SUV\_ZEV\_percentage})\cdot(\text{ZEV\_HC}) \ldots \\ +(\text{Total\_Worcester\_miles})\cdot(\text{SUV\_on\_road})\cdot(\text{SUV\_SLEV\_percentage})\cdot(\text{SLEV\_HC}) \ldots \\ +(\text{Total\_Worcester\_miles})\cdot(\text{SUV\_on\_road})\cdot(\text{SUV\_T1\_percentage})\cdot(\text{T1\_HC}) \ldots \\ +(\text{Total\_Worcester\_miles})\cdot(\text{SUV\_on\_road})\cdot(\text{SUV\_TLEV\_percentage})\cdot(\text{TLEV\_HC}) \ldots \\ +(\text{Total\_Worcester\_miles})\cdot(\text{SUV\_on\_road})\cdot(\text{SUV\_LEV\_percentage})\cdot(\text{LEV\_HC}) \ldots \\ +[(\text{Total\_Worcester\_miles})\cdot(\text{SUV\_on\_road})\cdot(\text{SUV\_ULEV\_percentage})\cdot(\text{ULEV\_HC})] \ldots \\ +(\text{Total\_Worcester\_miles})\cdot\left(SUV_{Hybrid}\right)\cdot(\text{SLEV\_HC})\end{array}\right]$$

$$SUV_{HC} = 1.184 \times 10^7 \text{ gm}$$

$$SUV_{CO} := V_{9602}\cdot\left[\begin{array}{l}(Total\_Worcester\_miles)\cdot(SUV\_on\_road)\cdot(SUV\_ZEV\_percentage)\cdot(ZEV\_CO)\ ... \\ +(Total\_Worcester\_miles)\cdot(SUV\_on\_road)\cdot(SUV\_SLEV\_percentage)\cdot(SLEV\_CO)\ ... \\ +(Total\_Worcester\_miles)\cdot(SUV\_on\_road)\cdot(SUV\_T1\_percentage)\cdot(T1\_CO)\ ... \\ +(Total\_Worcester\_miles)\cdot(SUV\_on\_road)\cdot(SUV\_TLEV\_percentage)\cdot(TLEV\_CO)\ ... \\ +(Total\_Worcester\_miles)\cdot(SUV\_on\_road)\cdot(SUV\_LEV\_percentage)\cdot(LEV\_CO)\ ... \\ +[(Total\_Worcester\_miles)\cdot(SUV\_on\_road)\cdot(SUV\_ULEV\_percentage)\cdot(ULEV\_CO)]\ ... \\ +(Total\_Worcester\_miles)\cdot\left(SUV_{Hybrid}\right)\cdot(SLEV\_CO)\end{array}\right]$$

$$SUV_{CO} = 2.578\times 10^{8}\ gm$$

Emissions Due to New Small Cars

$$SmC_{NOx} := V_{9602}\cdot\left[\begin{array}{l}(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_ZEV\_percentage)\cdot(ZEV\_NOx)\ ... \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_SLEV\_percentage)\cdot(SLEV\_NOx)\ ... \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_T1\_percentage)\cdot(T1\_NOx)\ ... \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_TLEV\_percentage)\cdot(TLEV\_NOx)\ ... \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_LEV\_percentage)\cdot(LEV\_NOx)\ ... \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_ULEV\_percentage)\cdot(ULEV\_NOx)\end{array}\right]$$

$$SmC_{NOx} = 2.401\times 10^{7}\ gm$$

$$SmC_{HC} := V_{9602}\cdot\left[\begin{array}{l}(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_ZEV\_percentage)\cdot(ZEV\_HC)\ ... \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_SLEV\_percentage)\cdot(SLEV\_HC)\ ... \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_T1\_percentage)\cdot(T1\_HC)\ ... \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_TLEV\_percentage)\cdot(TLEV\_HC)\ ... \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_LEV\_percentage)\cdot(LEV\_HC)\ ... \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_ULEV\_percentage)\cdot(ULEV\_HC)\end{array}\right]$$

$$SmC_{HC} = 1.018\times 10^{7}\ gm$$

$$SmC_{CO} := V_{9602}\cdot\left[\begin{array}{l}(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_ZEV\_percentage)\cdot(ZEV\_CO)\ ... \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_SLEV\_percentage)\cdot(SLEV\_CO)\ ... \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_T1\_percentage)\cdot(T1\_CO)\ ... \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_TLEV\_percentage)\cdot(TLEV\_CO)\ ... \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_LEV\_percentage)\cdot(LEV\_CO)\ ... \\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_ULEV\_percentage)\cdot(ULEV\_CO)\end{array}\right]$$

$$SmC_{CO} = 3.026\times 10^{8}\ gm$$

Emissions Due to New Large-Medium cars and Minivans

$$LMM_{NOx} := V_{9602}\cdot\left[\begin{array}{l}(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_ZEV\_percentage)\cdot(ZEV\_NOx)\ ... \\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_SLEV\_percentage)\cdot(SLEV\_NOx)\ ... \\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_T1\_percentage)\cdot(T1\_NOx)\ ... \\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_TLEV\_percentage)\cdot(TLEV\_NOx)\ ... \\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_LEV\_percentage)\cdot(LEV\_NOx)\ ... \\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_ULEV\_percentage)\cdot(ULEV\_NOx)\end{array}\right]$$

$$LMM_{NOx} = 4.817\times 10^{7}\ gm$$

$$LMM_{HC} := V_{9602}\cdot\left[\begin{array}{l}(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_ZEV\_percentage)\cdot(ZEV\_HC)\ ... \\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_SLEV\_percentage)\cdot(SLEV\_HC)\ ... \\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_T1\_percentage)\cdot(T1\_HC)\ ... \\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_TLEV\_percentage)\cdot(TLEV\_HC)\ ... \\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_LEV\_percentage)\cdot(LEV\_HC)\ ... \\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_ULEV\_percentage)\cdot(ULEV\_HC)\end{array}\right]$$

$$LMM_{HC} = 1.945\times 10^{7}\ gm$$

$$LMM_{CO} := V_{9602}\cdot\left[\begin{array}{l}(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_ZEV\_percentage)\cdot(ZEV\_CO)\ ... \\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_SLEV\_percentage)\cdot(SLEV\_CO)\ ... \\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_T1\_percentage)\cdot(T1\_CO)\ ... \\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_TLEV\_percentage)\cdot(TLEV\_CO)\ ... \\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_LEV\_percentage)\cdot(LEV\_CO)\ ... \\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_ULEV\_percentage)\cdot(ULEV\_CO)\end{array}\right]$$

$$LMM_{CO} = 6.634\times 10^{8}\ gm$$

Emissions Due to Vehicles manufactured 1995 or before:

Note: Prior to 1996 vehicles were generally classified as either Light Duty Vehicles (LDV) or Light Dut Trucks (LDT)

Recalculated Old Vehicle Distributions

$LDT\% := SUV_{old} \cdot \%NotReplaced \quad LDT\% = 0.15$

$LDT_{Hybrid} := SUV_{old} \cdot \%Hybrid \quad LDT_{Hybrid} = 0.05$

x100 percent distribution

$LDC\% := SmC_{old} + LMM_{old} \quad LDC\% = 0.8$

1992 to 1995 Emissions Data:

By 1992, all vehicles had to conform to the following Federal standard:

$$LDV\_9295_{CO} := 3.4 \cdot \frac{gm}{mi} \quad LDV\_9295_{HC} := 0.41 \cdot \frac{gm}{mi} \quad LDV\_9295_{NOx} := 1.0 \cdot \frac{gm}{mi}$$

$$LDT\_9295_{CO} := 10 \cdot \frac{gm}{mi} \quad LDT\_9295_{HC} := 0.67 \cdot \frac{gm}{mi} \quad LDT\_9295_{NOx} := 1.2 \cdot \frac{gm}{mi}$$

1982 - 1991 Emissions Data:

In this time frame, HC were not regulated. Instead Volatile Organic Compounds (VOC) were the standard, and will be considered nearly equivalent to HC's

Vehicles older than 1991 have reached their full usefull life of 10 yrs / 100,000 mi

$$LDV\_8291_{CO} := 4.2 \cdot \frac{gm}{mi} \quad LDV\_8291_{VOC} := 0.80 \cdot \frac{gm}{mi} \quad LDV\_8291_{NOx} := 1.0 \frac{gm}{mi}$$

$$LDT\_8291_{CO} := \frac{10 \cdot 8 + 18}{9} \cdot \frac{gm}{mi} \quad LDT\_8291_{VOC} := 0.80 \cdot \frac{gm}{mi} \quad LDT\_8291_{NOx} := 1.2 \cdot \frac{gm}{mi}$$

Pre 1982 Data:

$$LDV\_P82_{CO} := \frac{23 \cdot 2 + 39 \cdot 3 + 15 \cdot 5}{10} \cdot \frac{gm}{mi} \quad LDV\_P82_{NOx} := \frac{3 \cdot 3 + 3.1 \cdot 2 + 2 \cdot 4 + 1 \cdot 2}{11} \cdot \frac{gm}{mi}$$

$$LDV\_P82_{VOC} := \frac{3.4 \cdot 3 + 1.5 \cdot 5 + 0.41 \cdot 2}{10} \cdot \frac{gm}{mi}$$

$$LDT\_P82_{CO} := \frac{39 \cdot 3 + 20 \cdot 5 + 18 \cdot 4}{12} \cdot \frac{gm}{mi} \quad LDT\_P82_{VOC} := \frac{3.4 \cdot 3 + 2 \cdot 4 + 1.7 \cdot 6}{13} \cdot \frac{gm}{mi}$$

$$LDT\_P82_{NOx} := \frac{3 \cdot 3 + 3.1 \cdot 4 + 2.3 \cdot 6}{13} \cdot \frac{gm}{mi}$$

Emissions Calculations:

1992 - 1995

$$LDV9295_{CO} := V_{9295}\cdot(Total\_Worcester\_miles)\cdot LDV\_9295_{CO}\cdot LDC\% \quad LDV9295_{CO} = 7.2\times 10^{8}\,gm$$

$$LDT9295_{CO} := V_{9295}\cdot(Total\_Worcester\_miles)\cdot LDT\_9295_{CO}\cdot LDT\% \ldots + V_{9295}\cdot(Total\_Worcester\_miles)\cdot SLEV\_CO\cdot LDT_{Hybrid} \quad LDT9295_{CO} = 4.103\times 10^{8}\,gm$$

$$LDV9295_{NOx} := V_{9295}\cdot(Total\_Worcester\_miles)\cdot LDV\_9295_{NOx}\cdot LDC\% \quad LDV9295_{NOx} = 2.118\times 10^{8}\,gm$$

$$LDT9295_{NOx} := V_{9295}\cdot(Total\_Worcester\_miles)\cdot LDT\_9295_{NOx}\cdot LDT\% .. + V_{9295}\cdot(Total\_Worcester\_miles)\cdot SLEV\_NOx\cdot LDT_{Hybri} \quad LDT9295_{NOx} = 4.791\times 10^{7}\,gm$$

$$LDV9295_{HC} := V_{9295}\cdot(Total\_Worcester\_miles)\cdot LDV\_9295_{HC}\cdot LDC\% \quad LDV9295_{HC} = 8.683\times 10^{7}\,gm$$

$$LDT9295_{HC} := V_{9295}\cdot(Total\_Worcester\_miles)\cdot LDT\_9295_{HC}\cdot LDT\% \ldots + V_{9295}\cdot(Total\_Worcester\_miles)\cdot SLEV\_HC\cdot LDT_{Hybrid} \quad LDT9295_{HC} = 2.674\times 10^{7}\,gm$$

1982-1991

$$LDV8291_{CO} := V_{8291}\cdot(Total\_Worcester\_miles)\cdot LDV\_8291_{CO}\cdot LDC\% \quad LDV8291_{CO} = 6.523\times 10^{8}\,gm$$

$$LDT8291_{CO} := V_{8291}\cdot(Total\_Worcester\_miles)\cdot LDT\_8291_{CO}\cdot LDT\% \ldots + V_{8291}\cdot(Total\_Worcester\_miles)\cdot SLEV\_CO\cdot LDT_{Hybrid} \quad LDT8291_{CO} = 3.268\times 10^{8}\,gm$$

$$LDV8291_{NOx} := V_{8291}\cdot(Total\_Worcester\_miles)\cdot LDV\_8291_{NOx}\cdot LDC\% \quad LDV8291_{NOx} = 1.553\times 10^{8}\,gm$$

$$LDT8291_{NOx} := V_{8291}\cdot(Total\_Worcester\_miles)\cdot LDT\_8291_{NOx}\cdot LDT\% .. + V_{8291}\cdot(Total\_Worcester\_miles)\cdot SLEV\_NOx\cdot LDT_{Hybri} \quad LDT8291_{NOx} = 3.514\times 10^{7}\,gm$$

$$LDV8291_{VOC} := V_{8291}\cdot(Total\_Worcester\_miles)\cdot LDV\_8291_{VOC}\cdot LDC\% \quad LDV8291_{VOC} = 1.242\times 10^{8}\,gm$$

$$LDT8291_{VOC} := V_{8291}\cdot(Total\_Worcester\_miles)\cdot LDT\_8291_{VOC}\cdot LDT\% \ldots + V_{8291}\cdot(Total\_Worcester\_miles)\cdot SLEV\_HC\cdot LDT_{Hybrid} \quad LDT8291_{VOC} = 2.339\times 10^{7}\,gm$$

Pre 1982

$$LDVP82_{CO} := V_{P82}\cdot(Total\_Worcester\_miles)\cdot LDV\_P82_{CO}\cdot LDC\% \quad LDVP82_{CO} = 5.04\times 10^{8}\,gm$$

$$LDTP82_{CO} := V_{P82}\cdot(Total\_Worcester\_miles)\cdot LDT\_P82_{CO}\cdot LDT\% \ldots + V_{P82}\cdot(Total\_Worcester\_miles)\cdot SLEV\_CO\cdot LDT_{Hybrid} \quad LDTP82_{CO} = 9.695\times 10^{7}\,gm$$

$$LDVP82_{NOx} := V_{P82}\cdot(Total\_Worcester\_miles)\cdot LDV\_P82_{NOx}\cdot LDC\% \quad LDVP82_{NOx} = 4.852\times 10^{7}\,gm$$

$$LDTP82_{NOx} := V_{P82}\cdot(Total\_Worcester\_miles)\cdot LDT\_P82_{NOx}\cdot LDT\% \ldots + V_{P82}\cdot(Total\_Worcester\_miles)\cdot SLEV\_NOx\cdot LDT_{Hybrid} \quad LDTP82_{NOx} = 1.078\times 10^{7}\,gm$$

$$LDVP82_{VOC} := V_{P82}\cdot(Total\_Worcester\_miles)\cdot LDV\_P82_{VOC}\cdot LDC\% \qquad LDVP82_{VOC} = 3.922\times 10^{7}\,gm$$

$$LDTP82_{VOC} := V_{P82}\cdot(Total\_Worcester\_miles)\cdot LDT\_P82_{VOC}\cdot LDT\% \ldots + V_{P82}\cdot(Total\_Worcester\_miles)\cdot SLEV\_HC\cdot LDT_{Hybrid} \qquad LDTP82_{VOC} = 8.688\times 10^{6}\,gm$$

Total Emissions of New Vehicles, (English Tons):

Carbon Monoxide:

$$CO_{new} := LMM_{CO} + SmC_{CO} + SUV_{CO}$$

$$CO_{new} = 1349\,ton$$

$LMM_{CO} = 731.3\,ton$

$SmC_{CO} = 333.6\,ton$

$SUV_{CO} = 284.2\,ton$

Nitrous Oxides:

$$NOx_{new} := LMM_{NOx} + SmC_{NOx} + SUV_{NOx}$$

$$NOx_{new} = 106.3\,ton$$

$LMM_{NOx} = 53.1\,ton$

$SmC_{NOx} = 26.5\,ton$

$SUV_{NOx} = 26.7\,ton$

Hydocarbons:

$$HC_{new} := LMM_{HC} + SmC_{HC} + SUV_{HC}$$

$$HC_{new} = 45.7\,ton$$

$LMM_{HC} = 21.4\,ton$

$SmC_{HC} = 11.2\,ton$

$SUV_{HC} = 13\,ton$

Total Emissions:

$$Emissions_{new} := CO_{new} + NOx_{new} + HC_{new}$$

$$Emissions_{new} = 1501\,ton$$

Total Emissions of Older Vehicles, (English Tons):

Carbon Monoxide:

$LDV9295_{CO} = 793.7\,ton$ $LDV8291_{CO} = 719\,ton$ $LDVP82_{CO} = 555.6\,ton$

$LDT9295_{CO} = 452.3\,ton$ $LDT8291_{CO} = 360.2\,ton$ $LDTP82_{CO} = 106.9\,ton$

$$CO_{old} := LDV9295_{CO} + LDT9295_{CO} + LDV8291_{CO} + LDT8291_{CO} \ldots + LDVP82_{CO} + LDTP82_{CO}$$

$$CO_{old} = 2987.7\,ton$$

Nitrous Oxides:

$LDV9295_{NOx} = 233.4\,ton$ $LDV8291_{NOx} = 171.2\,ton$ $LDVP82_{NOx} = 53.5\,ton$

$LDT9295_{NOx} = 52.8\,ton$ $LDT8291_{NOx} = 38.7\,ton$ $LDTP82_{NOx} = 11.9\,ton$

$$NOx_{old} := LDV9295_{NOx} + LDT9295_{NOx} + LDV8291_{NOx} + LDT8291_{NOx} \ldots + LDVP82_{NOx} + LDTP82_{NOx}$$

$$NOx_{old} = 561.5\,ton$$

HydroCarbons and Volatile Organic Compounds:

$LDV9295_{HC} = 95.7\,ton$ $LDV8291_{VOC} = 137\,ton$ $LDVP82_{VOC} = 43.2\,ton$

$LDT9295_{HC} = 29.5\,ton$ $LDT8291_{VOC} = 25.8\,ton$ $LDTP82_{VOC} = 9.6\,ton$

$$HC_{old} := LDV9295_{HC} + LDT9295_{HC} + LDV8291_{VOC} + LDT8291_{VOC} \ldots + LDVP82_{VOC} + LDTP82_{VOC}$$

$HC_{old} = 340.7\,ton$

Totals for Older Vehicles:

$CO_{old} = 2987.7\,ton$ $NOx_{old} = 561.5\,ton$ $HC_{old} = 340.7\,ton$

$Emissions_{old} := CO_{old} + NOx_{old} + HC_{old}$

$Emissions_{old} = 3890\,ton$

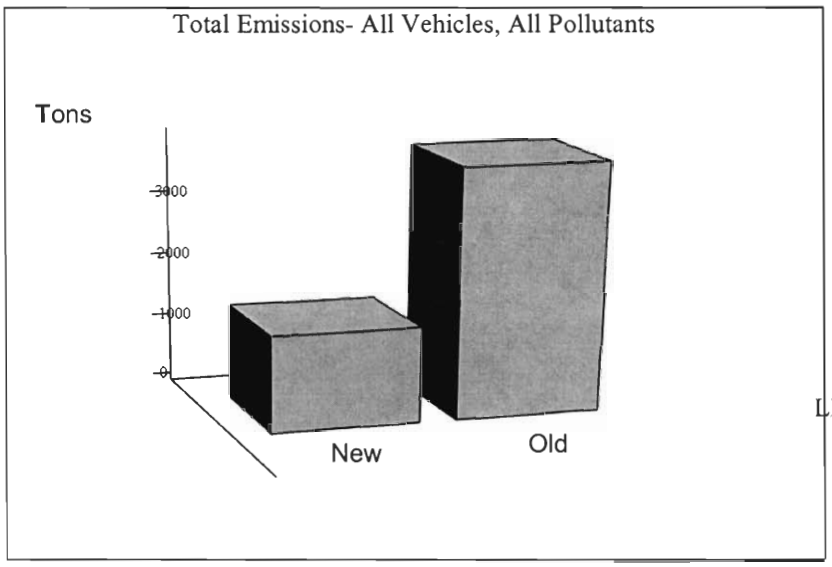
$T := Emissions_{new} + Emissions_{old}$ $T = 5391\,ton$

$CO_{Tot} := CO_{new} + CO_{old}$ $CO_{Tot} = 4336.7\,ton$

$NOx_{Tot} := NOx_{new} + NOx_{old}$ $NOx_{Tot} = 667.832\,ton$

$HC_{Tot} := HC_{old} + HC_{new}$ $HC_{Tot} = 386.455\,ton$

$$Graph1 := \left(\frac{Emissions_{new}}{2000} \quad \frac{Emissions_{old}}{2000} \right)$$



$LDTP82_{VOC} = 12.7\,ton$

Replacing 50% of all LDT's w/Hybrids

billion_miles := $10^9 \cdot mi$

million_miles := $10^6 \cdot mi$

Assumptions:

Vehicles traveling through Worcester Travel an average of 7 miles each

Travel_distance := $7 \cdot mi$

40% of the pollutants in the air come from vehicles

Work_days := $261 \cdot day$

Week_ends := $104 \cdot day$

City Data:

Worcester_population := 254900 people

Vehicles_per_person := 0.79

Percentages of Vehicle Types:

%NotReplaced := 0.5 %Hybrid := 0.5

Newer Vehicles:

SUV := 0.275 SmC := 0.21 LMM := 0.51

Older Vehicles:

SUV_{old} := 0.20 SmC_{old} := 0.20 LMM_{old} := 0.60

Age distribution of Vehicles on the Roads:

1996 - 2002 V_{9602} := 0.45

1992 - 1995 V_{9295} := 0.30

1982 - 1991 V_{8291} := 0.22

Pre 1982 V_{P82} := 0.03

Transitional Low Emissions Vehicle Data:

TLEV_NMOG := $0.125 \cdot \frac{gm}{mi}$ TLEV_NOx := $0.4 \cdot \frac{gm}{mi}$

TLEV_CO := $3.4 \cdot \frac{gm}{mi}$ TLEV_HCHO := $0.015 \cdot \frac{gm}{mi}$

TLEV HC := TLEV NMOG + TLEV_HCHO

TLEV_HC = $0.14 \frac{gm}{mi}$

Low Emissions Vehicle Data:

LEV_NMOG := $0.075 \cdot \frac{gm}{mi}$ LEV_NOx := $0.2 \cdot \frac{gm}{mi}$

LEV_CO := $3.4 \cdot \frac{gm}{mi}$ LEV_HCHO := $0.015 \cdot \frac{gm}{mi}$

LEV_HC := LEV_NMOG + LEV_HCHO

LEV_HC = $0.09 \frac{gm}{mi}$

Ultra Low Emissions Vehicle Data:

$$ULEV\_NMOG := 0.04 \cdot \frac{gm}{mi} \qquad ULEV\_NOx := 0.2 \cdot \frac{gm}{mi}$$

$$ULEV\_CO := 1.7 \cdot \frac{gm}{mi} \qquad ULEV\_HCHO := 0.008 \cdot \frac{gm}{mi}$$

$$ULEV\_HC := ULEV\_NMOG + ULEV\_HCHO$$

$$ULEV\_HC = 0.048 \frac{gm}{mi}$$

Super Low Emissions Vehicle Data:

$$SLEV\_CO := 1.0 \cdot \frac{gm}{mi} \qquad SLEV\_HC := 0.01 \cdot \frac{gm}{mi} \qquad SLEV\_NOx := 0.02 \cdot \frac{gm}{mi}$$

Zero Emissions Vehicle Data:

$$ZEV\_CO := 0 \cdot \frac{gm}{mi} \qquad ZEV\_HC := 0 \cdot \frac{gm}{mi} \qquad ZEV\_NOx := 0 \cdot \frac{gm}{mi}$$

Tier 1 Emissions Data:

$$T1\_CO := 4.2 \cdot \frac{gm}{mi} \qquad T1\_HC := 0.31 \cdot \frac{gm}{mi} \qquad T1\_NOx := 0.6 \cdot \frac{gm}{mi}$$

Tabulated Vehicle Distribution for New Vehicles:

$$SUV\_ZEV\_percentage := \frac{0.21}{100} \qquad LMM\_ZEV\_percentage := 0$$

$$SUV\_SLEV\_percentage := \frac{0.86}{100} \qquad LMM\_SLEV\_percentage := \frac{0.36}{100}$$

$$SUV\_ULEV\_percentage := \frac{4.5}{100} \qquad LMM\_ULEV\_percentage := \frac{19.13}{100}$$

$$SUV\_LEV\_percentage := \frac{51.82}{100} \qquad LMM\_LEV\_percentage := \frac{70.40}{100}$$

$$SUV\_TLEV\_percentage := \frac{1.5}{100} \qquad LMM\_TLEV\_percentage := \frac{7.94}{100}$$

$$SUV\_T1\_percentage := \frac{41.11}{100} \qquad LMM\_T1\_percentage := \frac{2.17}{100}$$

$$SmC\_ZEV\_percentage := \frac{0.26}{100} \qquad SmC\_LEV\_percentage := \frac{65.17}{100}$$

$$SmC\_SLEV\_percentage := \frac{1.06}{100} \qquad SmC\_TLEV\_percentage := \frac{9.5}{100}$$

$$SmC\_ULEV\_percentage := \frac{15.04}{100} \qquad SmC\_T1\_percentage := \frac{8.97}{100}$$

Percentages of Each New Vehicle Type Observed on the Road:

SmC_on_road := .2395 LMM_on_road := .5418

SUV_on_road := .2187·%NotReplaced SUV_{Hybrid} := 0.2187·%Hybrid

Equations:

Number_of_Vehicles := Worcester_population·Vehicles_per_person

$Number\_of\_Vehicles = 2.014 \times 10^{5}$

$$Commuter\_miles := (Travel\_distance)\cdot\left(\frac{2}{day}\right)\cdot(Work\_days)\cdot(Number\_of\_Vehicles)$$

Commuter_miles = 0.736 billion_miles driven per year

$$Avg\_commuter\_miles := \frac{Commuter\_miles}{Number\_of\_Vehicles} \qquad Avg\_commuter\_miles = 3.654 \times 10^{3}\ \frac{mi}{\text{per vehicle driven per year}}$$

$$Weekend\_miles := \left(\frac{Travel\_distance}{2}\right)\cdot\left(\frac{2}{day}\right)\cdot(Week\_ends)\cdot(Number\_of\_Vehicles)$$

Weekend_miles = 146.598 million_milesriven per year

$$Avg\_weekend\_miles := \frac{Weekend\_miles}{Number\_of\_Vehicles} \qquad Avg\_weekend\_miles = 728\ \frac{mi}{\text{per vehicle driven per year}}$$

Total_Worcester_miles := Weekend_miles + Commuter_miles Total_Worcester_miles = 0.882 billion_miles driven per year

Emissions Due to New SUV's

$$SUV_{NOx} := V_{9602}\cdot\left[\begin{array}{l}(Total\_Worcester\_miles)\cdot(SUV\_on\_road)\cdot(SUV\_ZEV\_percentage)\cdot(ZEV\_NOx)\ \ldots\\ +(Total\_Worcester\_miles)\cdot(SUV\_on\_road)\cdot(SUV\_SLEV\_percentage)\cdot(SLEV\_NOx)\ \ldots\\ +(Total\_Worcester\_miles)\cdot(SUV\_on\_road)\cdot(SUV\_T1\_percentage)\cdot(T1\_NOx)\ \ldots\\ +(Total\_Worcester\_miles)\cdot(SUV\_on\_road)\cdot(SUV\_TLEV\_percentage)\cdot(TLEV\_NOx)\ \ldots\\ +(Total\_Worcester\_miles)\cdot(SUV\_on\_road)\cdot(SUV\_LEV\_percentage)\cdot(LEV\_NOx)\ \ldots\\ +[(Total\_Worcester\_miles)\cdot(SUV\_on\_road)\cdot(SUV\_ULEV\_percentage)\cdot(ULEV\_NOx)]\ \ldots\\ +(Total\_Worcester\_miles)\cdot\left(SUV_{Hybrid}\right)\cdot(SLEV\_NOx)\end{array}\right]$$

$SUV_{NOx} = 1.674 \times 10^{7}$ gm

$$SUV_{HC} := V_{9602}\cdot\left[\begin{array}{l}(Total\_Worcester\_miles)\cdot(SUV\_on\_road)\cdot(SUV\_ZEV\_percentage)\cdot(ZEV\_HC)\ \ldots\\ +(Total\_Worcester\_miles)\cdot(SUV\_on\_road)\cdot(SUV\_SLEV\_percentage)\cdot(SLEV\_HC)\ \ldots\\ +(Total\_Worcester\_miles)\cdot(SUV\_on\_road)\cdot(SUV\_T1\_percentage)\cdot(T1\_HC)\ \ldots\\ +(Total\_Worcester\_miles)\cdot(SUV\_on\_road)\cdot(SUV\_TLEV\_percentage)\cdot(TLEV\_HC)\ \ldots\\ +(Total\_Worcester\_miles)\cdot(SUV\_on\_road)\cdot(SUV\_LEV\_percentage)\cdot(LEV\_HC)\ \ldots\\ +[(Total\_Worcester\_miles)\cdot(SUV\_on\_road)\cdot(SUV\_ULEV\_percentage)\cdot(ULEV\_HC)]\ \ldots\\ +(Total\_Worcester\_miles)\cdot\left(SUV_{Hybrid}\right)\cdot(SLEV\_HC)\end{array}\right]$$

$SUV_{HC} = 8.182 \times 10^{6}$ gm

$$SUV_{CO} := V_{9602}\cdot\left[\begin{array}{l}(Total\_Worcester\_miles)\cdot(SUV\_on\_road)\cdot(SUV\_ZEV\_percentage)\cdot(ZEV\_CO)\ ...\\ +(Total\_Worcester\_miles)\cdot(SUV\_on\_road)\cdot(SUV\_SLEV\_percentage)\cdot(SLEV\_CO)\ ...\\ +(Total\_Worcester\_miles)\cdot(SUV\_on\_road)\cdot(SUV\_T1\_percentage)\cdot(T1\_CO)\ ...\\ +(Total\_Worcester\_miles)\cdot(SUV\_on\_road)\cdot(SUV\_TLEV\_percentage)\cdot(TLEV\_CO)\ ...\\ +(Total\_Worcester\_miles)\cdot(SUV\_on\_road)\cdot(SUV\_LEV\_percentage)\cdot(LEV\_CO)\ ...\\ +[(Total\_Worcester\_miles)\cdot(SUV\_on\_road)\cdot(SUV\_ULEV\_percentage)\cdot(ULEV\_CO)]\ ...\\ +(Total\_Worcester\_miles)\cdot\left(SUV_{Hybrid}\right)\cdot(SLEV\_CO)\end{array}\right]$$

$$SUV_{CO} = 2.008\times 10^{8}\ gm$$

Emissions Due to New Small Cars

$$SmC_{NOx} := V_{9602}\cdot\left[\begin{array}{l}(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_ZEV\_percentage)\cdot(ZEV\_NOx)\ ...\\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_SLEV\_percentage)\cdot(SLEV\_NOx)\ ...\\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_T1\_percentage)\cdot(T1\_NOx)\ ...\\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_TLEV\_percentage)\cdot(TLEV\_NOx)\ ...\\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_LEV\_percentage)\cdot(LEV\_NOx)\ ...\\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_ULEV\_percentage)\cdot(ULEV\_NOx)\end{array}\right]$$

$$SmC_{NOx} = 2.401\times 10^{7}\ gm$$

$$SmC_{HC} := V_{9602}\cdot\left[\begin{array}{l}(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_ZEV\_percentage)\cdot(ZEV\_HC)\ ...\\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_SLEV\_percentage)\cdot(SLEV\_HC)\ ...\\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_T1\_percentage)\cdot(T1\_HC)\ ...\\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_TLEV\_percentage)\cdot(TLEV\_HC)\ ...\\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_LEV\_percentage)\cdot(LEV\_HC)\ ...\\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_ULEV\_percentage)\cdot(ULEV\_HC)\end{array}\right]$$

$$SmC_{HC} = 1.018\times 10^{7}\ gm$$

$$SmC_{CO} := V_{9602}\cdot\left[\begin{array}{l}(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_ZEV\_percentage)\cdot(ZEV\_CO)\ ...\\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_SLEV\_percentage)\cdot(SLEV\_CO)\ ...\\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_T1\_percentage)\cdot(T1\_CO)\ ...\\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_TLEV\_percentage)\cdot(TLEV\_CO)\ ...\\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_LEV\_percentage)\cdot(LEV\_CO)\ ...\\ +(Total\_Worcester\_miles)\cdot(SmC\_on\_road)\cdot(SmC\_ULEV\_percentage)\cdot(ULEV\_CO)\end{array}\right]$$

$$SmC_{CO} = 3.026\times 10^{8}\ gm$$

Emissions Due to New Large-Medium cars and Minivans

$$LMM_{NOx} := V_{9602}\cdot\begin{bmatrix} (Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_ZEV\_percentage)\cdot(ZEV\_NOx) \ldots \\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_SLEV\_percentage)\cdot(SLEV\_NOx) \ldots \\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_T1\_percentage)\cdot(T1\_NOx) \ldots \\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_TLEV\_percentage)\cdot(TLEV\_NOx) \ldots \\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_LEV\_percentage)\cdot(LEV\_NOx) \ldots \\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_ULEV\_percentage)\cdot(ULEV\_NOx) \end{bmatrix}$$

$$LMM_{NOx} = 4.817 \times 10^{7}\,gm$$

$$LMM_{HC} := V_{9602}\cdot\begin{bmatrix} (Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_ZEV\_percentage)\cdot(ZEV\_HC) \ldots \\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_SLEV\_percentage)\cdot(SLEV\_HC) \ldots \\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_T1\_percentage)\cdot(T1\_HC) \ldots \\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_TLEV\_percentage)\cdot(TLEV\_HC) \ldots \\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_LEV\_percentage)\cdot(LEV\_HC) \ldots \\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_ULEV\_percentage)\cdot(ULEV\_HC) \end{bmatrix}$$

$$LMM_{HC} = 1.945 \times 10^{7}\,gm$$

$$LMM_{CO} := V_{9602}\cdot\begin{bmatrix} (Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_ZEV\_percentage)\cdot(ZEV\_CO) \ldots \\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_SLEV\_percentage)\cdot(SLEV\_CO) \ldots \\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_T1\_percentage)\cdot(T1\_CO) \ldots \\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_TLEV\_percentage)\cdot(TLEV\_CO) \ldots \\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_LEV\_percentage)\cdot(LEV\_CO) \ldots \\ +(Total\_Worcester\_miles)\cdot(LMM\_on\_road)\cdot(LMM\_ULEV\_percentage)\cdot(ULEV\_CO) \end{bmatrix}$$

$$LMM_{CO} = 6.634 \times 10^{8}\,gm$$

Emissions Due to Vehicles manufactured 1995 or before:

Note: Prior to 1996 vehicles were generally classified as either Light Duty Vehicles (LDV) or Light Dut Trucks (LDT)

Recalculated Old Vehicle Distributions

$LDT\% := SUV_{old} \cdot \%NotReplaced \quad LDT\% = 0.1$

$LDT_{Hybrid} := SUV_{old} \cdot \%Hybrid \quad LDT_{Hybrid} = 0.1$

$LDC\% := SmC_{old} + LMM_{old} \quad LDC\% = 0.8$

x100 percent distribution

1992 to 1995 Emissions Data:

By 1992, all vehicles had to conform to the following Federal standard:

$LDV\_9295_{CO} := 3.4 \cdot \frac{gm}{mi} \quad LDV\_9295_{HC} := 0.41 \cdot \frac{gm}{mi} \quad LDV\_9295_{NOx} := 1.0 \cdot \frac{gm}{mi}$

$LDT\_9295_{CO} := 10 \cdot \frac{gm}{mi} \quad LDT\_9295_{HC} := 0.67 \cdot \frac{gm}{mi} \quad LDT\_9295_{NOx} := 1.2 \cdot \frac{gm}{mi}$

1982 - 1991 Emissions Data:

In this time frame, HC were not regulated. Instead Volatile Organic Compounds (VOC) were the standard, and will be considered nearly equivalent to HC's

Vehicles older than 1991 have reached their full usefull life of 10 yrs / 100,000 mi

$LDV\_8291_{CO} := 4.2 \cdot \frac{gm}{mi} \quad LDV\_8291_{VOC} := 0.80 \cdot \frac{gm}{mi} \quad LDV\_8291_{NOx} := 1.0 \frac{gm}{mi}$

$LDT\_8291_{CO} := \frac{10 \cdot 8 + 18}{9} \cdot \frac{gm}{mi} \quad LDT\_8291_{VOC} := 0.80 \cdot \frac{gm}{mi} \quad LDT\_8291_{NOx} := 1.2 \cdot \frac{gm}{mi}$

Pre 1982 Data:

$LDV\_P82_{CO} := \frac{23 \cdot 2 + 39 \cdot 3 + 15 \cdot 5}{10} \cdot \frac{gm}{mi} \quad LDV\_P82_{NOx} := \frac{3 \cdot 3 + 3.1 \cdot 2 + 2 \cdot 4 + 1 \cdot 2}{11} \cdot \frac{gm}{mi}$

$LDV\_P82_{VOC} := \frac{3.4 \cdot 3 + 1.5 \cdot 5 + 0.41 \cdot 2}{10} \cdot \frac{gm}{mi}$

$LDT\_P82_{CO} := \frac{39 \cdot 3 + 20 \cdot 5 + 18 \cdot 4}{12} \cdot \frac{gm}{mi} \quad LDT\_P82_{VOC} := \frac{3.4 \cdot 3 + 2 \cdot 4 + 1.7 \cdot 6}{13} \cdot \frac{gm}{mi}$

$LDT\_P82_{NOx} := \frac{3 \cdot 3 + 3.1 \cdot 4 + 2.3 \cdot 6}{13} \cdot \frac{gm}{mi}$

Emissions Calculations:

1992 - 1995

$LDV9295_{CO} := V_{9295} \cdot (Total\_Worcester\_miles) \cdot LDV\_9295_{CO} \cdot LDC\%$ $LDV9295_{CO} = 7.2 \times 10^{8}\ gm$

$LDT9295_{CO} := V_{9295} \cdot (Total\_Worcester\_miles) \cdot LDT\_9295_{CO} \cdot LDT\% \ldots + V_{9295} \cdot (Total\_Worcester\_miles) \cdot SLEV\_CO \cdot LDT_{Hybrid}$ $LDT9295_{CO} = 2.912 \times 10^{8}\ gm$

$LDV9295_{NOx} := V_{9295} \cdot (Total\_Worcester\_miles) \cdot LDV\_9295_{NOx} \cdot LDC\%$ $LDV9295_{NOx} = 2.118 \times 10^{8}\ gm$

$LDT9295_{NOx} := V_{9295} \cdot (Total\_Worcester\_miles) \cdot LDT\_9295_{NOx} \cdot LDT\% .. + V_{9295} \cdot (Total\_Worcester\_miles) \cdot SLEV\_NOx \cdot LDT_{Hybri}$ $LDT9295_{NOx} = 3.23 \times 10^{7}\ gm$

$LDV9295_{HC} := V_{9295} \cdot (Total\_Worcester\_miles) \cdot LDV\_9295_{HC} \cdot LDC\%$ $LDV9295_{HC} = 8.683 \times 10^{7}\ gm$

$LDT9295_{HC} := V_{9295} \cdot (Total\_Worcester\_miles) \cdot LDT\_9295_{HC} \cdot LDT\% \ldots + V_{9295} \cdot (Total\_Worcester\_miles) \cdot SLEV\_HC \cdot LDT_{Hybrid}$ $LDT9295_{HC} = 1.8 \times 10^{7}\ gm$

1982-1991

$LDV8291_{CO} := V_{8291} \cdot (Total\_Worcester\_miles) \cdot LDV\_8291_{CO} \cdot LDC\%$ $LDV8291_{CO} = 6.523 \times 10^{8}\ gm$

$LDT8291_{CO} := V_{8291} \cdot (Total\_Worcester\_miles) \cdot LDT\_8291_{CO} \cdot LDT\% \ldots + V_{8291} \cdot (Total\_Worcester\_miles) \cdot SLEV\_CO \cdot LDT_{Hybrid}$ $LDT8291_{CO} = 2.308 \times 10^{8}\ gm$

$LDV8291_{NOx} := V_{8291} \cdot (Total\_Worcester\_miles) \cdot LDV\_8291_{NOx} \cdot LDC\%$ $LDV8291_{NOx} = 1.553 \times 10^{8}\ gm$

$LDT8291_{NOx} := V_{8291} \cdot (Total\_Worcester\_miles) \cdot LDT\_8291_{NOx} \cdot LDT\% .. + V_{8291} \cdot (Total\_Worcester\_miles) \cdot SLEV\_NOx \cdot LDT_{Hybri}$ $LDT8291_{NOx} = 2.368 \times 10^{7}\ gm$

$LDV8291_{VOC} := V_{8291} \cdot (Total\_Worcester\_miles) \cdot LDV\_8291_{VOC} \cdot LDC\%$ $LDV8291_{VOC} = 1.242 \times 10^{8}\ gm$

$LDT8291_{VOC} := V_{8291} \cdot (Total\_Worcester\_miles) \cdot LDT\_8291_{VOC} \cdot LDT\% \ldots + V_{8291} \cdot (Total\_Worcester\_miles) \cdot SLEV\_HC \cdot LDT_{Hybric}$ $LDT8291_{VOC} = 1.572 \times 10^{7}\ gm$

Pre 1982

$LDVP82_{CO} := V_{P82} \cdot (Total\_Worcester\_miles) \cdot LDV\_P82_{CO} \cdot LDC\%$ $LDVP82_{CO} = 5.04 \times 10^{8}\ gm$

$LDTP82_{CO} := V_{P82} \cdot (Total\_Worcester\_miles) \cdot LDT\_P82_{CO} \cdot LDT\% \ldots + V_{P82} \cdot (Total\_Worcester\_miles) \cdot SLEV\_CO \cdot LDT_{Hybrid}$ $LDTP82_{CO} = 6.64 \times 10^{7}\ gm$

$LDVP82_{NOx} := V_{P82} \cdot (Total\_Worcester\_miles) \cdot LDV\_P82_{NOx} \cdot LDC\%$ $LDVP82_{NOx} = 4.852 \times 10^{7}\ gm$

$LDTP82_{NOx} := V_{P82} \cdot (Total\_Worcester\_miles) \cdot LDT\_P82_{NOx} \cdot LDT\% \ldots + V_{P82} \cdot (Total\_Worcester\_miles) \cdot SLEV\_NOx \cdot LDT_{Hybrid}$ $LDTP82_{NOx} = 7.221 \times 10^{6}\ gm$

$$LDVP82_{VOC} := V_{P82}\cdot(Total\_Worcester\_miles)\cdot LDV\_P82_{VOC}\cdot LDC\% \qquad LDVP82_{VOC} = 3.922\times 10^{7}\,gm$$

$$LDTP82_{VOC} := V_{P82}\cdot(Total\_Worcester\_miles)\cdot LDT\_P82_{VOC}\cdot LDT\% \ldots + V_{P82}\cdot(Total\_Worcester\_miles)\cdot SLEV\_HC\cdot LDT_{Hybrid} \qquad LDTP82_{VOC} = 5.81\times 10^{6}\,gm$$

Total Emissions of New Vehicles, (English Tons):

Carbon Monoxide:

$$CO_{new} := LMM_{CO} + SmC_{CO} + SUV_{CO}$$

$$CO_{new} = 1286.2\,ton$$

$LMM_{CO} = 731.3\,ton$

$SmC_{CO} = 333.6\,ton$

$SUV_{CO} = 221.3\,ton$

Nitrous Oxides:

$$NOx_{new} := LMM_{NOx} + SmC_{NOx} + SUV_{NOx}$$

$$NOx_{new} = 98\,ton$$

$LMM_{NOx} = 53.1\,ton$

$SmC_{NOx} = 26.5\,ton$

$SUV_{NOx} = 18.5\,ton$

Hydocarbons:

$$HC_{new} := LMM_{HC} + SmC_{HC} + SUV_{HC}$$

$$HC_{new} = 41.7\,ton$$

$LMM_{HC} = 21.4\,ton$

$SmC_{HC} = 11.2\,ton$

$SUV_{HC} = 9\,ton$

Total Emissions:

$$Emissions_{new} := CO_{new} + NOx_{new} + HC_{new}$$

$$Emissions_{new} = 1425.9\,ton$$

Total Emissions of Older Vehicles, (English Tons):

Carbon Monoxide:

$LDV9295_{CO} = 793.7\,ton$ $LDV8291_{CO} = 719\,ton$ $LDVP82_{CO} = 555.6\,ton$

$LDT9295_{CO} = 321\,ton$ $LDT8291_{CO} = 254.4\,ton$ $LDTP82_{CO} = 73.2\,ton$

$$CO_{old} := LDV9295_{CO} + LDT9295_{CO} + LDV8291_{CO} + LDT8291_{CO} \ldots + LDVP82_{CO} + LDTP82_{CO}$$

$$CO_{old} = 2716.9\,ton$$

Nitrous Oxides:

$LDV9295_{NOx} = 233.4\,ton$ $LDV8291_{NOx} = 171.2\,ton$ $LDVP82_{NOx} = 53.5\,ton$

$LDT9295_{NOx} = 35.6\,ton$ $LDT8291_{NOx} = 26.1\,ton$ $LDTP82_{NOx} = 8\,ton$

$$NOx_{old} := LDV9295_{NOx} + LDT9295_{NOx} + LDV8291_{NOx} + LDT8291_{NOx} \ldots + LDVP82_{NOx} + LDTP82_{NOx}$$

$$NOx_{old} = 527.8\,ton$$

HydroCarbons and Volatile Organic Compounds:

$LDV9295_{HC} = 95.7\,ton$ $LDV8291_{VOC} = 137\,ton$ $LDVP82_{VOC} = 43.2\,ton$

$LDT9295_{HC} = 19.8\,ton$ $LDT8291_{VOC} = 17.3\,ton$ $LDTP82_{VOC} = 6.4\,ton$

$$HC_{old} := LDV9295_{HC} + LDT9295_{HC} + LDV8291_{VOC} + LDT8291_{VOC} \cdots + LDVP82_{VOC} + LDTP82_{VOC}$$

$$HC_{old} = 319.5\,ton$$

Totals for Older Vehicles:

$CO_{old} = 2716.9\,ton$ $NOx_{old} = 527.8\,ton$ $HC_{old} = 319.5\,ton$

$$Emissions_{old} := CO_{old} + NOx_{old} + HC_{old}$$

$$Emissions_{old} = 3564.2\,ton$$

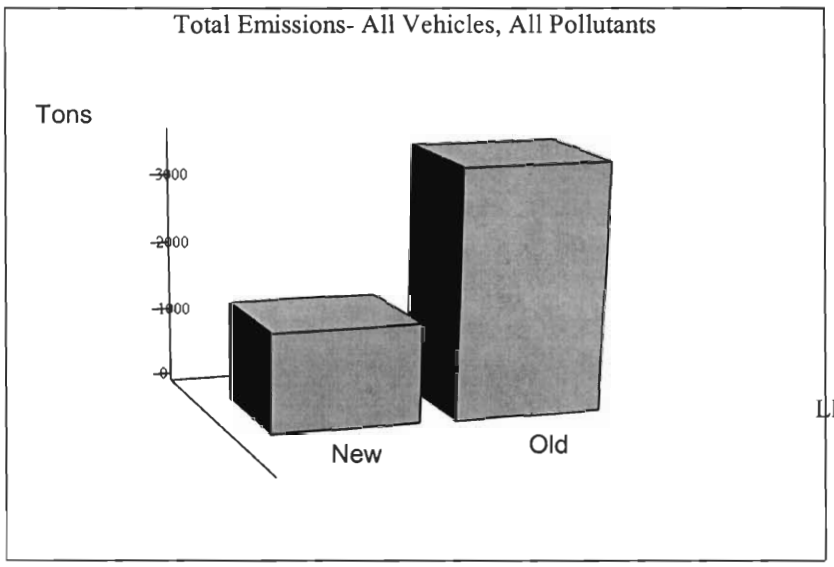
$T := Emissions_{new} + Emissions_{old}$ $T = 4990\,ton$

$CO_{Tot} := CO_{new} + CO_{old}$ $CO_{Tot} = 4003.1\,ton$

$NOx_{Tot} := NOx_{new} + NOx_{old}$ $NOx_{Tot} = 625.801\,ton$

$HC_{Tot} := HC_{old} + HC_{new}$ $HC_{Tot} = 361.169\,ton$

$$Graph1 := \left(\frac{Emissions_{new}}{2000} \quad \frac{Emissions_{old}}{2000} \right)$$



$LDTP82_{VOC} = 12.7\,ton$