ARIZONA DEPARTMENT OF TRANSPORTATION

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# THE COST EFFECTIVENESS AND MAGNITUDE OF POTENTIAL IMPACT OF VARIOUS CONGESTION MANAGEMENT MEASURES

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16. Abstract

Phoenix and Tucson are "non-attainment" areas under the EPA's air quality guidelines. Vehicle traffic is the main man-made source of the region's air quality problems. Various methods for reducing the vehicular contribution to air pollution are constantly under consideration and debate. The potential impact on air quality of each measure varies. Each measure also has a different price associated with it. At the same time, there are limited resources available to fund these measures.

The original contribution of this report is contained in the translation of congestion abatement impacts into air quality impacts. The air quality estimates are calculated using numbers specific to Phoenix and Tucson. The methodology permits comparison of the available congestion abatement options by the potential magnitude of emissions reductions and by cost-effectiveness of removing pollutants. The near term (within five years) results are summarized in the Tables A1 through A4, for Phoenix and Tucson, respectively.

The purpose of this report is to provide policy makers with a guide to options that are available to reduce congestion that may lead to a more cost-effective program for reducing vehicle generated air pollution.

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# METRIC (SI*) CONVERSION FACTORS

## APPROXIMATE CONVERSIONS TO SI UNITS

| Symbol | When You Know | Multiply By | To Find | Symbol |
|---|---|---|---|---|
| | | **LENGTH** | | |
| in | inches | 2.54 | centimeters | cm |
| ft | feet | 0.3048 | meters | m |
| yd | yards | 0.914 | meters | m |
| mi | miles | 1.61 | kilometers | km |
| | | **AREA** | | |
| $in^2$ | square inches | 6.452 | centimeters squared | $cm^2$ |
| $ft^2$ | square feet | 0.0929 | meters squared | $m^2$ |
| $yd^2$ | square yards | 0.836 | meters squared | $m^2$ |
| $mi^2$ | square miles | 2.59 | kilometers squared | $km^2$ |
| ac | acres | 0.395 | hectares | ha |
| | | **MASS (weight)** | | |
| oz | ounces | 28.35 | grams | g |
| lb | pounds | 0.454 | kilograms | kg |
| T | short tons (2000 lb) | 0.907 | megagrams | Mg |
| | | **VOLUME** | | |
| fl oz | fluid ounces | 29.57 | milliliters | mL |
| gal | gallons | 3.785 | liters | L |
| $ft^3$ | cubic feet | 0.0328 | meters cubed | $m^3$ |
| $yd^3$ | cubic yards | 0.765 | meters cubed | $m^3$ |

Note: Volumes greater than 1000 L shall be shown in $m^3$.

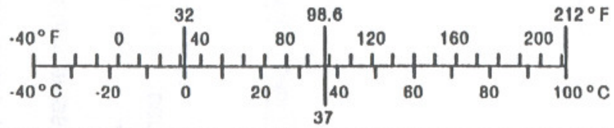
| Symbol | When You Know | Multiply By | To Find | Symbol |
|---|---|---|---|---|
| | | **TEMPERATURE (exact)** | | |
| °F | Fahrenheit temperature | 5/9 (after subtracting 32) | Celsius temperature | °C |

These factors conform to the requirement of FHWA Order 5190.1A

*SI is the symbol for the International System of Measurements

## APPROXIMATE CONVERSIONS TO SI UNITS

| Symbol | When You Know | Multiply By | To Find | Symbol |
|---|---|---|---|---|
| | | **LENGTH** | | |
| mm | millimeters | 0.039 | inches | in |
| m | meters | 3.28 | feet | ft |
| yd | meters | 1.09 | yards | yd |
| km | kilometers | 0.621 | miles | mi |
| | | **AREA** | | |
| $mm^2$ | millimeters squared | 0.0016 | square inches | $in^2$ |
| $m^2$ | meters squared | 10.764 | square feet | $ft^2$ |
| $yd^2$ | kilometers squared | 0.39 | square miles | $mi^2$ |
| ha | hectares (10,000 $m^2$) | 2.53 | acres | ac |
| | | **MASS (weight)** | | |
| g | grams | 0.0353 | ounces | oz |
| kg | kilograms | 2.205 | pounds | lb |
| Mg | megagrams (1000 kg) | 1.103 | short tons | T |
| | | **VOLUME** | | |
| mL | millimeters | 0.034 | fluid ounces | fl oz |
| L | liters | 0.264 | gallons | gal |
| $m^3$ | meters cubed | 35.315 | cubic feet | $ft^3$ |
| $m^3$ | meters cubed | 1.308 | cubic yards | $yd^3$ |
| | | **TEMPERATURE (exact)** | | |
| °C | Celsius temperature | 9/5 (then add 32) | Fahrenheit temperature | °F |



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# Executive Summary

## Purpose

It has been estimated that vehicle travel in the Phoenix and Tucson areas is approximately 60 million and 15 million miles per weekday, respectively. Emissions from these vehicles contribute to the high pollutant counts that have caused the EPA to declare the cities to be areas of "non-attainment" by federal standards. Traffic congestion, resulting from widespread reliance on the automobile for transportation, exacerbates the problem by reducing travel speeds to below optimal levels. There has been much discussion concerning possible solutions to alleviating traffic congestion and pollution. The purpose of this report is to provide policy makers with a guide to options that are available to reduce congestion that may lead to lower levels of pollution. The congestion abatement measures that have been reviewed here are compared by the magnitude of emissions reductions and the cost-effectiveness of achieving those reductions.

The congestion abatement measures usually discussed can generally be described as either supply-side or demand-side remedies. Supply-side measures include adding capacity to existing highways and increasing public transit. Demand-side measures seek to decrease the demand for automobile travel by creating incentives that discourage single-occupancy vehicle (SOV) travel. It is important to remember, however, that the effectiveness of any congestion abatement measure will depend on other measures that either are or are not in place. For example, the effectiveness of travel demand management programs (TDMs) to reduce SOV travel is very much dependent on the availability of alternatives such as public transit and HOV facilities. Therefore, an estimate of any individual measure's effect on congestion will depend on the assumptions made about other measures in place.

## Methodology

Optimistic assumptions have been made when calculating estimated impacts. Every attempt is made to view each available option in a favorable light while keeping expectations within reason. It is the goal of this report to provide a starting point for policy makers exploring the available options and not to provide definitive recommendations. It is suggested that there be further research into any option that is seriously considered for implementation.

This report is based primarily on past research concerning congestion abatement measures. It is assumed that if a policy or measure is actually implemented in Phoenix or Tucson the result will be comparable to results reported elsewhere. However, it is very likely that Phoenix and Tucson possess characteristics that are very different from those cities that past research has studied. Attempts have been made to account for those differences that may significantly alter the effect that a measure might have. In some cases it has been possible to evaluate measures already in place in the two cities.

The original contribution of this report is contained in the translation of congestion abatement impacts into air quality impacts. The air quality estimates are calculated using numbers specific to Phoenix and Tucson.

Some congestion abatement measures impact all motorists and have larger impacts on congestion. Other measures are targeted at travel to and from employment sites and therefore affect a smaller portion of all vehicle travel. Some measures require large expenditures while others will only have small costs associated with implementation. Some measures are very effective when certain local characteristics exist and ineffective if those characteristics are not present. There is a large body of literature devoted to studies of the effectiveness of congestion abatement. The writing of this report follows a comprehensive review of the literature on the effectiveness of congestion abatement. Many federal and state agencies commission evaluations of the projects that have been implemented. Many implemented projects have not yet been studied or the results are not yet available.

The expectations of the successful implementation of the reviewed measures have been converted to reductions in daily regional vehicle miles traveled (VMTs). It is believed that VMTs are the best measure of traffic levels. The levels of VMTs cited above are estimates provided by the Arizona Transportation Research Center (ATRC) and attributable to the MAGTPO and PAGTPO. The effect on air quality is estimated by multiplying the change in VMTs by the amount (measured in grams) of emissions per vehicle mile traveled. Estimates of emissions per vehicle mile traveled were obtained from the Arizona Department of Environmental Quality.[88] Costs have been estimated with Phoenix and Tucson in mind.

## Congestion Abatement Measures: Overview

The measures reviewed here have been categorized as follows:

### *Transportation Demand Management*

Transportation Demand Management (TDM) programs attempt to change commuting habits of single occupancy vehicle (SOV) users by encouraging high occupancy vehicle (HOV) use and/or promoting travel during off peak times. The typical individual commuter's travel decision is based on the perceived costs and benefits of each modal option. The factors entering the commute decision include money, time and convenience, among other things. An effective TDM program will sufficiently raise the cost of SOV travel relative to the HOV alternatives so that HOV travel becomes attractive. This may be done by directly raising the cost of SOV travel, or by lowering the perceived cost of HOV alternatives. Successful program implementation will reduce the number of vehicles using the road system while providing a wide variety of mobility options to those who wish to travel.

Employer-based TDM programs focus on reducing SOVs arriving to specific work sites. Employer TDM measures include company provision of ridematching, vanpools and financial incentives to encourage HOV use.

The major categories of TDMs are:

1) Ridesharing Services: Ridematching, Guaranteed Ride Home.
2) Parking Management.
3) Vanpool Programs, Transportation Allowances.
4) Telecommuting.
5) Flexible Work Scheduling.
6) Proximate Commuting.

*Regional Trip Reduction*

Effective TDM programs employ a wide variety of alternatives and strategies, each mutually supporting the overall objective of trip reduction. Area-wide programs in which a government agency may have the lead responsibility will seek to affect as many travelers as possible. TDM alternatives at the regional level can include:

1) Provision of preferential access for HOV users.
2) HOV: Priority Lanes and Preferential Access.
3) Congestion Pricing.
4) Park and Ride Facilities.

*Transportation System Improvements*

Improvements to the transportation system are intended to expand capacity of the system to transport people, maximize traffic flow within the system and reduce accident rates. Transportation system improvements discussed here include public transit and intelligent transportation systems.

The discussion of public transit includes analysis of several options for improving bus service as well as a discussion of the impact rail service will have on air quality.

The intelligent transportation systems examined here include traffic signal synchronization, freeway management systems, and incident management programs.

## Results

The methodology outlined above permits comparison of the available congestion abatement options by the potential magnitude of emissions reductions and by cost-effectiveness of removing pollutants. The near term (within five years) results are summarized in the Tables A1 and A3, for Phoenix and Tucson, respectively. The estimates presented here are based under certain assumptions that are discussed in Appendix B: Notes on Estimate Calculations. The estimated impacts are dependent on the assumptions made in calculating them. However, for most of the measures examined here dramatic changes in the assumptions will result in only small changes in the magnitude of their impacts.

**Table A-1: Emissions Reductions Policies Ranked by Order of Potential Magnitude**
(near term annual impacts for Phoenix region)

| **Policy** | **Cost** | **Pollutants Removed** | | **Cost/ Ton** |
|---|---|---|---|---|
| | millions of $ | tons/year | percentage | $ per ton |
| Signal Synchronization(California model) | 13.5 | 30,163 | 8.10% | 448 |
| Congestion Pricing | 1000 | 16,422 | 4.41% | 60,894 |
| Signal Synchronization(MCDOT estimate) | 25 | 9,310 | 2.50% | 2,685 |
| Signal Synchronization(Texas model) | 8.55 | 8,461 | 2.27% | 1,011 |
| Parking and Transportation Allowance | 110 | 6,594 | 1.77% | 16,682 |
| HOV Lanes | 32 | 5,218 | 1.40% | 6,133 |
| Compressed Work Week | nil | 5,218 | 1.40% | nil |
| Parking Management | 58 | 5,181 | 1.39% | 11,195 |
| Telecommuting Half Time | 3.446 | 4,227 | 1.14% | 815 |
| Maricopa County TDM Program | 1.8 | 3,438 | 0.92% | 524 |
| Transportation Allowance Program | 18 | 3,297 | 0.89% | 5,460 |
| Flex Time | nil | 3,061 | 0.82% | nil |
| High Bus Expansion | 144 | 3,049 | 0.82% | 47,229 |
| Natural Gas Bus Service | 74.7 | 2,304 | 0.62% | 32,422 |
| Bus Service | 66.5 | 2,077 | 0.56% | 32,017 |
| Telecommuting (1 day a week) | 3.446 | 1,691 | 0.45% | 2,038 |
| Proximate Commuting | nil | 1,629 | 0.44% | nil |
| Guaranteed Ride Home | 0.36 | 1,361 | 0.37% | 265 |
| Moderate Bus Expansion | 72 | 1,143 | 0.31% | 62,992 |
| Rail Transit(ValTrans model) | 530 | 1,089 | 0.29% | 486,685 |
| Ridematching Programs | 0.1 | 785 | 0.21% | 127 |
| Vanpooling | 0.4 | 364 | 0.10% | 1,099 |
| Rail Transit(20 mile, at grade) | 56.6 | 150 | 0.04% | 377,333 |
| Park and Ride | 0.181 | 63 | 0.02% | 2,873 |

**Table A-3: Emissions Reductions Policies Ranked by Order of Potential Magnitude**
(near term annual impacts for Tucson region)

| Policy | Cost | Pollutants Removed | | Cost/ Ton |
|---|---|---|---|---|
| | millions of $ | tons/year | percentage | $ per ton |
| Congestion Pricing | 250 | 4141 | 4.45% | 60,372 |
| Natural Gas Bus Service | 35 | 1078 | 1.16% | 32,468 |
| Parking and Transportation Allowance | 20 | 1067 | 1.15% | 18,744 |
| Bus Service | 34 | 941 | 1.01% | 36,132 |
| Parking Management | 10.7 | 839 | 0.90% | 12,753 |
| Compressed Work Week | nil | 839 | 0.90% | nil |
| Telecommuting Half Time | 0.554 | 680 | 0.73% | 815 |
| Transportation Allowance Program | 3.4 | 534 | 0.57% | 6,367 |
| Flex Time | nil | 495 | 0.53% | nil |
| Telecommuting (1 day a week) | 0.554 | 272 | 0.29% | 2,037 |
| Guaranteed Ride Home | 0.063 | 272 | 0.29% | 232 |
| Proximate Commuting | nil | 261 | 0.28% | nil |
| Ridematching Programs | 0.1 | 127 | 0.14% | 787 |

# Introduction

This report examines a wide array of congestion abatement measures and examines their impact on air pollution. The report was primarily written for the Phoenix and Tucson, Arizona areas, but the information presented here may be of value to transportation and environmental planners anywhere.

Most of the measures examined here have only small impacts on air pollution. This is because most of these policies are intended to reduce the vehicle miles traveled (VMTs) of commuters. Commuters account for only 38% of all VMTs in Phoenix and about 19% in Tucson. Commuters also drive vehicles (cars and light pick-up trucks) that emit less air pollutants than the average of all vehicles (which includes heavy duty gasoline and diesel powered vehicles). Therefore, measures that target only commuters have relatively small impacts on air pollution. Measures that affect all traffic, like congestion pricing or traffic light synchronization, will likely have larger effects on air pollution.

Tables in Appendix A summarize the effectiveness of the measures we examined. The measures are evaluated based on their effects on air pollution and on their costs. The effects on air pollution listed in these tables are short term estimates. In the long term (more than five years) the effects of these measures on air pollution will decline. There are three reasons for this:

1. Latent Demand. During times of excessive traffic congestion there are many people who choose not to drive at that time in order to avoid the congestion. If the traffic congestion is mitigated these people may choose to drive when they previously chose not to drive. If enough of this "latent" traffic takes to the road the congestion returns.

2. Fleet Turnover. Since older cars and trucks are continually being retired and the new cars and trucks that replace them emit less air pollutants, the average emissions per vehicle mile will decline over time. Thus, removing a certain number of vehicles from the road today will have a greater effect on air pollution than removing the same number of cars some time in the future. This effect is a factor with hydrocarbon (HC) and carbon monoxide (CO) emissions which are expected to decline by 4% to 5% a year over the next few decades. Turnover will not have as salutary effects on particulate matter. While diesel engines (the main vehicle emission source of particulates) may become cleaner running, increased traffic volume will tend to stir up more dust, offsetting some of the gains from cleaner diesel burning.[1] In addition, new technologies that are on the horizon ("cold start catalytic converter" and improved catalytic converter insulation [92]) may significantly reduce per mile vehicle emissions. Consequently, the air would tend to become cleaner despite increased traffic volumes. As a result, each SOV removed from the roads will have a smaller impact on air quality in the future.

3. Growth. Traffic in the Phoenix region is expected to increase by nearly 60% between 1996 and 2020. This growth may offset the air pollution reductions resulting from any of the policies discussed here.

The results from this study have interesting implications relating to the ability of congestion abatement techniques to translate into significant reductions in pollution levels. Many of these measures are targeted at commuters traveling to employment sites. Therefore, since these policies and programs are focused at reducing SOV trips to work their impact on pollutants is diluted because of travel not affected by TDM programs (i.e., non-work trips, commercial vehicles, and "latent demand").

The apparent expense and difficulty of achieving significant pollution reductions through congestion management suggest a different approach to the problem. It is difficult to significantly alter people's driving habits so that they will drive less. Many programs that attempt to do this must, by design, focus on a small subset of the driving public. An alternative plan might specifically seek to remove high-polluting vehicles from the road. A program of this type, such as the "smog-dog" Remote Emissions Sensing program currently in use on a small scale in Phoenix, would enforce strict emissions laws by monitoring vehicles on the roadways. A cost-effectiveness study exploring a larger scale deployment of this type of program might reveal an attractive alternative to costly congestion management measures.

# Methodology

This report is meant to evaluate policies based upon their impact on traffic congestion and air quality. It is true that some of these policies may have benefits other than traffic and air pollution mitigation, but these benefits are not the focus of this study.

The measure chosen to estimate a policy's effect on traffic is its effect on daily vehicle miles traveled (VMTs). The number of daily VMTs is perhaps the best estimate available for the level of traffic. Currently, estimates of daily VMTs in the Phoenix and Tucson areas are 60 million and 15 million, respectively. These numbers are expected to increase to 95 million and 27 million, respectively, by 2020. These estimates are based on phone discussions with representatives from MAGTPO and PAGTPO.

The effect on air pollution is estimated by multiplying the change in VMTs by estimates of the grams of emissions per vehicle mile traveled. Estimates of the grams of emissions of hydrocarbons, carcon monoxide, and nitrous oxide per vehicle mile traveled were obtained from the Arizona Department of Transportation's Environmental Planning Section, Technical Analysis Branch. The estimates are for the winter season emissions and based on an average vehicle speed of 30 miles per hour. It is believed that using these assumptions will give us a reasonable first approximation of the potential impacts of the various congestion mitigation measures. The estimates for PM10 were obtained via a phone conversation with a representative from ADEQ. Once policy makers have selected a few measures for possible implementation, it is our recommendation that a more sophisticated analysis be performed using the models available to both ADOT and the Arizona Department of Environmental Quality. The estimates are summarized below:

**Table M-1: 1996 Emissions Estimates: Grams Per Vehicle Mile**

| | HC | CO | NOX | PM10 | Total |
|---|---|---|---|---|---|
| passenger vehicles | 2.76 | 11.96 | 1.67 | 0.07 | 16.46 |
| diesel vehicles | 3.06 | 7.22 | 6.97 | 1.65 | 18.90 |
| average of all vehicles | 2.89 | 12.38 | 1.85 | 0.15 | 17.27 |

**Table M-2: 1996 Emissions Estimates: Tons Per 1,000,000 Vehicle Miles**
(907,000 grams/ton)

| | HC | CO | NOX | PM10 | Total |
|---|---|---|---|---|---|
| passenger vehicles | 3.04 | 13.19 | 1.84 | 0.08 | 18.15 |
| diesel vehicles | 3.37 | 7.96 | 7.68 | 1.82 | 20.84 |
| average of all vehicles | 3.19 | 13.65 | 2.04 | 0.17 | 19.04 |

**Table M-3: 1996 Emissions Estimates: Tons Per Weekday for Phoenix**

| | HC | CO | NOX | PM10 | Total |
|---|---|---|---|---|---|
| average of all vehicles | 191 | 819 | 122 | 10 | 1143 |

**Table M-4: 1996 Emissions Estimates: Tons Per Weekend Day for Phoenix**

| | HC | CO | NOX | PM10 | Total |
|---|---|---|---|---|---|
| average of all vehicles | 126 | 541 | 81 | 7 | 754 |

**Table M-5: 1996 Emissions Estimates: Tons Per Year for Phoenix**

| | HC | CO | NOX | PM10 | Total |
|---|---|---|---|---|---|
| average of all vehicles | 62305 | 266965 | 39884 | 3234 | 372388 |

**Table M-6: 1996 Emissions Estimates: Tons Per Weekday for Tucson**

| | HC | CO | NOX | PM10 | Total |
|---|---|---|---|---|---|
| average of all vehicles | 48 | 205 | 31 | 2 | 286 |

**Table M-7: 1996 Emissions Estimates: Tons Per Weekend Day for Tucson**

| | HC | CO | NOX | PM10 | Total |
|---|---|---|---|---|---|
| average of all vehicles | 32 | 135 | 20 | 2 | 189 |

**Table M-8: 1996 Emissions Estimates: Tons Per Year for Tucson**

| | HC | CO | NOX | PM10 | Total |
|---|---|---|---|---|---|
| average of all vehicles | 15576 | 66741 | 9971 | 808 | 93097 |

**Table M-9: 2020 Emissions Estimates: Grams Per Vehicle Mile**

| | HC | CO | NOX | PM10 | Total |
|---|---|---|---|---|---|
| passenger vehicles | 0.83 | 8.33 | 1.21 | 0.06 | 10.43 |
| diesel vehicles | 1.51 | 7.15 | 5.77 | 1.41 | 15.84 |
| average of all vehicles | 0.87 | 8.56 | 1.33 | 0.15 | 10.91 |

**Table M-10: 2020 Emissions Estimates: Tons Per 1,000,000 Vehicle Miles**

| | HC | CO | NOX | PM10 | Total |
|---|---|---|---|---|---|
| passenger vehicles | 0.92 | 9.18 | 1.33 | 0.07 | 11.50 |
| diesel vehicles | 1.66 | 7.88 | 6.36 | 1.55 | 17.46 |
| average of all vehicles | 0.96 | 9.44 | 1.47 | 0.17 | 12.03 |

**Table M-11: 2020 Emissions Estimates: Tons Per Weekday for Phoenix**

| | HC | CO | NOX | PM10 | Total |
|---|---|---|---|---|---|
| average of all vehicles | 91 | 897 | 139 | 16 | 1143 |

**Table M-12: 2020 Emissions Estimates: Tons Per Weekend Day for Phoenix**

| | HC | CO | NOX | PM10 | Total |
|---|---|---|---|---|---|
| average of all vehicles | 60 | 592 | 92 | 10 | 754 |

**Table M-13: 2020 Emissions Estimates: Tons Per Year for Phoenix**

| | HC | CO | NOX | PM10 | Total |
|---|---|---|---|---|---|
| average of all vehicles | 29698 | 292196 | 45400 | 5120 | 372414 |

**Table M-14: 2020 Emissions Estimates: Tons Per Weekday for Tucson**

| | HC | CO | NOX | PM10 | Total |
|---|---|---|---|---|---|
| average of all vehicles | 26 | 255 | 40 | 4 | 325 |

**Table M-15: 2020 Emissions Estimates: Tons Per Weekend Day for Tucson**

| | HC | CO | NOX | PM10 | Total |
|---|---|---|---|---|---|
| average of all vehicles | 17 | 168 | 26 | 3 | 214 |

**Table M-16: 2020 Emissions Estimates: Tons Per Year for Tucson**

| | HC | CO | NOX | PM10 | Total |
|---|---|---|---|---|---|
| average of all vehicles | 8440 | 83045 | 12903 | 1455 | 105844 |

Emissions of carbon monoxide (CO) and particulate matter less than ten microns in diameter (PM10) are considered to be health problems in and of themselves. Hydro-carbons (HC, also known as volatile organic compounds, VOC) become a health problem only when they interact with sunlight to form ozone. The hydro-carbon reductions discussed here are not directly comparable to any reductions in ozone. This is because hydro-carbon emissions are only one factor among many associated with ozone production. Nitrous oxide is responsible for the development of acid rain. Acid rain is not considered a problem in Arizona due to its lack of rain and its highly alkaline soil.

It must be emphasized that this report concerns only *vehicle* emissions. All other sources of emissions (e.g. lawn mowers, laundromats, etc.) are ignored. All percent changes in emissions reported here are percent changes in vehicle emissions not total emissions. The percent change in total emissions would be smaller than the percent change in vehicle emissions.

To estimate the potential impacts of measures implemented in Arizona, evaluation studies conducted on programs and policies implemented elsewhere have been examined. The estimates presented here are based on the optimistic assumptions that the measures will be implemented under favorable conditions and the results will be in the medium to high range of those reported in the literature. The assumption that the policies discussed here will have near the maximum reported effect on VMTs is intended to present a "best-case" scenario. These estimates should serve as a reasonable starting point for further investigation into possible congestion abatement measures for the improvement of air quality. Where possible, the effects of programs implemented within the state of Arizona and the respective costs associated have been included in the estimates.

# Transportation Demand Management Programs: An Overview

## Description

Transportation Demand Management (TDM) programs attempt to change commuting habits of single occupancy vehicle (SOV) users by encouraging high occupancy vehicle (HOV) use and/or promoting travel during off peak times. The typical individual commuter's travel decision is based on the perceived costs and benefits of each modal option. The factors entering the commute decision include money, time and convenience, among other things. An effective TDM program will sufficiently raise the cost of SOV travel relative to the HOV alternatives so that HOV travel becomes attractive. This may be done by directly raising the cost of SOV travel, or by lowering the perceived cost of HOV alternatives. Successful program implementation would reduce the number of vehicles using the road system while providing a variety of mobility options to those who wish to travel.

TDM programs could employ a variety of alternatives and strategies, each mutually supporting the overall objective of trip reduction [2]. Area-wide programs in which a government agency may have the lead responsibility will seek to affect as many travelers as possible. TDM alternatives at the regional level would include service improvements to transit services, provision of preferential access for HOV users, and application of area-wide cost surcharges or subsidy measures. Employer-based TDM programs focus on reducing SOVs arriving to specific worksites. Employer TDM measures include company provision of ridematching, vanpools and financial incentives to encourage HOV use. The employer may also implement employee "flex-time" scheduling and/or allow telecommuting from home or satellite work stations.

*Trip Reduction Methods*

**Employer-Based**

- Ridesharing
  - ridematching
  - guaranteed ride home
  - parking management
  - vanpool programs
  - transportation allowances
- Telecommuting
- Flexible Work Scheduling
- Proximate Commuting

**Regional**

- HOV: Priority Lanes and Preferential Access
- Congestion Pricing
- Park and Ride Lots

**Effectiveness**

The literature concerned with the effectiveness of trip reduction measures contains mixed results. Estimates of TDM effectiveness vary widely. This is due, in part, to the difficulties inherent in data collection and research methodology. Major studies attempting to determine the effectiveness of TDM programs have used different methodologies and assumptions and, as a result, have arrived at different, incomparable results [3]. With these difficulties in mind, the summary findings of some major studies are discussed below.

There is some evidence that regional TDM programs are capable of contributing to significant reductions of SOV travel. One study of area-wide programs found trip reduction achievements ranging from 2.4 to 17.8 percent [4]. A Phoenix study of Maricopa County Trip Reduction Ordinance found approximately a 4 percent reduction in SOV travel among employees and a 13 percent reduction for students, after the first year of compliance [5]. After five years, the area SOV modal share of transportation to employment sites has declined from 82 to 76 percent, a 7 percent reduction in SOVs [7]. Several studies have examined data from the largest regional TDM program ever initiated in the US, California's Rule 1501 (formerly known as Regulation XV). The results indicate a decrease in SOV travel of about 5 to 10 percent [5], [10]. However, many researchers indicate a belief that TDM programs have not yet achieved their full potential [2], [4], [7], [9]. Others have reported declining HOV use after initial gains, suggesting the permanent effects of TDM programs may be less than what early participation indicates [5], [10].

At the employer level, some TDM programs have posted impressive reductions in SOV arrivals to the work site. Under optimal conditions, SOV trip reduction can reach 30 to 40 percent at a specific work site [2], [4]. Employer based TDM programs tend to be more effective because they can be tailored to individual worksite characteristics, market demographics, and trip making patterns. Information dissemination can be targeted to a well-defined set of employees, and a corporate culture can be created that supports the TDM objectives [2]. Whether a rate of trip reduction of up to 40 percent is attainable as a norm has not been determined. Some sites are more conducive to increases in HOV use from TDM programs.

The strategies and circumstances that are associated with the most effective employer TDM programs, measured in terms of vehicle trip reduction at the site, are:

- subsidies for those who use commute alternatives
- controlled parking, in terms of price and supply
- a mandatory or regulated environment requiring employers to reduce trips [6]

It is widely accepted that the effectiveness of area-wide TDM programs depend significantly on the type and level of participation of employers. Therefore, the development of TDM programs should be approached from the perspective of how public officials and local employers can work together to achieve trip reduction while maintaining availability of modal choice.

**Cost**

The direct costs for implementing TDM programs are borne by government agencies and employers. Employees bear some of the costs of TDM programs as well. The regulating agencies of a mandated regional TDM program will incur considerable costs in the form of developing the program and managing it. Programs that rely on intensive review of plans need to have sufficient staff to develop policies and practices. Employers face costs associated with developing and administering their site specific TDM program. Some of these costs can be transferred to the government through the use of subsidies. Many employers have reported favorable cost-benefit ratios. However, much of the savings is attributed to the lower cost of providing employee parking. The cost to employers associated with Rule 1501 was approximately $70-80 per employee [3]. Actual net costs to the employer may be positive or negative, depending on the employer’s cost of providing employee parking. Many intangible benefits also have been cited by employers: reduced absenteeism, enhanced corporate image, reduced employee tardiness, etc. [11].

**Conclusions**

The evidence is that a carefully developed TDM program that includes monetary incentives to commuters will be effective in reducing congestion. Employer provided subsidies for alternative travel have been a characteristic of successful programs [6]. Area-wide programs would be more effective if they include some form of congestion pricing measures. The HOV alternative most often chosen has been ridesharing. Therefore, government efforts to encourage car/vanpooling would seem likely to have the most significant effect.

# Employer-Based TDM Measures: Ridesharing

## Description

The most often used alternative to SOV commutes to the workplace is sharing a ride with co-workers in either a car or vanpool. Ridesharing is slightly more costly in terms of time and convenience than SOV travel. However, ridesharing affords a cost savings to the commuter by way of reduced travel expenses. Employers may try to encourage ridesharing among workers through the implementation of several programs.

## Effectiveness

Most programs are most effective when packaged with other programs that are mutually concerned with providing incentives for employee ridesharing. The availability of alternatives to SOV travel as well as site and region specific commute characteristics are factors which will influence any program's effectiveness.

## Guaranteed Ride Home

A guaranteed ride home (GRH) program assures commuters that rideshare or use transit that they will have transportation available should an emergency arise. Lack of back-up transportation is often cited as an important reason why many commuters do not rideshare [12]. The service may provide employees with a free ride home in a taxi or rental car in the event of emergencies during the work shift.

The evidence suggests that a GRH program will encourage some commuters who would not otherwise use alternative transportation to do so. The existence of a program could increase rideshare participation by perhaps 10 percent. While each ride home provided may be expensive, the infrequent use of this option accounts for a low annual cost. Many existing programs have experienced little abuse of the service. The service appears to provide peace of mind to commuters, although they may never find a need to use it.

A study of one of the first employment centers to offer the service concluded that of the eligible commuters only three percent actually used the service. Only three percent of those who did use the service used it more than once. The average cost was found to be $53 per ride. While the per ride cost is high, the service was used very infrequently. [13]

## Ridematching

Employers may provide a service of matching commuters to share rides to facilitate the use of car or vanpools. The service usually consists of a database which contains information used to determine which employees have the highest potential for sharing a ride. This information is then disseminated to the commuters. Continued efforts to validate and update the accuracy of the information are necessary.

Ridematching effectiveness in terms of successful placements will vary from program to program. Successful programs can place up to 60 percent of the registered commuters. However, effectiveness will depend not so much on the structure of the program, although certain characteristics can have marginal effects. The characteristics of the commute environment will determine the level of effectiveness. Ridematching programs will only be effective to the degree that there exists strong incentives for workers to seek alternatives to SOV travel. [14] There is no evidence that the mere existence of a ridematching program will significantly affect rideshare rates. It appears that other measures must be in place that will encourage use of the ridematching service.

### Vanpool Programs

Vanpool programs offer assistance to companies and individuals in the formation of vanpool groups. Commuters are given the incentive to participate in vanpools by the cost savings associated with ridesharing. The Regional Public Transportation Authority operates a third-party vanpool program in the Phoenix area. Currently, there are 103 vans in use each carrying 7 to 15 passengers. The program is 53% subsidized by federal and local funding. Fare revenues make up the remaining 47% of operating costs. The average round trip of each van is 60.4 miles, which implies that vanpool participants may live farther from their place of employment than the typical commuter. The program provides approximately 361,000 passenger trips per year that may have otherwise been served by SOVs.

### Parking Management

Many employers provide free parking to employees. This is no less than a subsidy to employees that drive and represents a financial incentive to drive alone. There is a cost to the employer to provide parking, therefore free parking is considered a benefit to employees. Because the IRS exempts employer-paid parking subsidies from income taxation, employers are encouraged to provide free parking to their employees.[15] Reducing or removing the parking subsidy is a method of raising the cost of the SOV commute.

There are many ways to incorporate parking into an employer-based TDM program. Employers may offer a cash-out option to employees, allowing the commuter to accept the cash equivalent of the employers' cost of providing parking. The employer may charge for parking at full or reduced cost to employees. Free or reduced parking may be provided for ridesharing commuters only. The optimal design depends on the commute environment and may be site specific.

The monthly charge for employee parking on-site has been found to be the single most influential factor for determining the percent of employees that drive alone to work in one study of urban TDM programs.[16] Several studies have estimated or determined that a parking charge coupled with a transit/carpool subsidy will decrease SOV commuter travel by 20-30 percent.[15] [16] [17] However, results of this magnitude are also correlated with off-site parking restrictions and availability of alternative transportation. Without the presence of these two characteristics, such strong results are not to be expected.

## Transportation Allowances

Transportation allowance programs provide subsidies to employees in one form or another and include transit fare allowances or subsidies, vanpool fare allowances, parking allowances or free parking, and general travel allowances that can be used by the employees toward any mode they choose or for any non-transportation purposes.[17]

Evidence suggests transit and ridesharing allowances have a modest impact on modal shares at employment sites. When packaged with other TDM measures like information dissemination, preferential parking for carpools, on-site transportation coordinator, etc., such programs have reduced SOV commuter travel up to 5 or 10 percent. Much greater reductions in SOV commuter driving (up to 30 percent) have been achieved at employment sites where transit and ridesharing incentives are packaged with parking charges for solo drivers or other parking orientated measures.[18]

## Cost

Implementation of employer-based programs will involve administrative costs as well as the cost of the subsidies provided. The programs can be designed to minimize cost of providing them for the employers. Optimal design will depend on the site characteristics: availability of alternative transportation, cost of providing parking, etc.. Some programs require a small start up cost while others may require significant capital investments or start-up costs. Generally the commuter receives a cost savings when taking advantage of a program and using alternatives to SOV travel. Employers may receive savings when the cost of providing parking is high, as well as intangible benefits that increase worker productivity.[19]

## Conclusions

Reducing or removing employer parking subsidies for employees is the single most effective measure to reduce drive alone rates to the work site. However, this measure is dependent on other factors such as availability of off-site parking and alternative transportation. In suburban areas, where transit access is often poor and where parking is usually plentiful and free of charge, generous alternate mode travel allowances are found to be necessary ingredients in successful TDM programs.[20]

# Employer Based TDM Measures: Telecommuting

## Description

Telecommuting refers to performing work at home, or at regional centers, that would traditionally have been performed at a centralized workplace. Regional centers include satellite offices maintained by employers and local centers maintained by local or state governments or by private firms where telecommuters from various organizations can work.

The rationale for telecommuting in terms of TDM is simple: Home based telecommuting reduces the total number of trips and regional center based telecommuting reduces the VMTs per trip.

## Effectiveness

Telecommuting appears to be very effective at reducing the VMTs of individuals who actually telecommute. The unanswered question is whether enough people can be encouraged to telecommute for this effect to significantly impact total VMTs and thus congestion and emissions.

The literature contains many studies that indicate that telecommuting reduces the VMTs of actual participants. A Minnesota pilot study reports that individual telecommuters on average saw a reduction of 15,936 miles traveled and 266 hours spent traveling over six months as a result of their reduced commuting. [21] A Texas pilot study reports that the average telecommuter reduces both total number of trips and VMTs by about 90% on days that they telecommute. [22] A Puget Sound based study that focused exclusively on center based telecommuting found that on days when individuals used the telecommuting center their VMTs declined from 63.25 to 29.31 per-person per-day. [23] Significantly, the literature suggests that most of the reduction in VMTs occurs during the morning and evening peak-commuting periods. [24]

As far as the effect of telecommuting on total VMTs is concerned there is very little empirical evidence to go on. However, the US D.O.T. has issued a report stating that a 1.6% participation rate in telecommuting will result in a reduction in total VMTs of 0.23% and in commuting VMTs of 0.7%. [24] The D.O.T. also points out that a concerted effort by public agencies to promote telecommuting could substantially increase the above numbers. Downs (1992) reports that telecommuting will have a minor effect on the total number of peak-hour trips. He estimates that even if 25% of all workers telecommute one day a week the total number of morning peak hour trips will be reduced by only 2.16%. Supposing 25% of workers telecommute half of the time results in a 5.39% reduction in morning peak hour trips. [25]

The participation rate is the key variable that will determine a telecommuting project’s effect on total VMTs. The Phoenix metropolitan area does have the potential for a high participation rate. Residential areas in the valley are very spread out and many people here have long commutes. Thus, many employees may find telecommuting to be desirable. Also, a relatively high percentage of workers in the valley perform the type of "information" work that effectively lends itself to telecommuting. As examples, the Arizona Department of Commerce, Energy Office reports that

20% of its workers are potential telecommuters and the Phoenix Transit System reports a potential participation rate of 75%. [26] It must be noted that the relatively high cost of ISDN lines (high speed data transmission lines) in Arizona may work against the proliferation of telecommuting here.

The effect of telecommuting on emissions may not be as simple as some other methods for reducing VMTs. While reducing the total VMTs will decrease total emissions, there is some concern that telecommuting could result in shorter and more frequent trips thus increasing emissions due to the "cold start" phenomena. [24] (Cars tend to emit more HCs and CO when they run cold.) Though this concern is valid conceptually, there seems to be no evidence that cold starts are currently an issue for the telecommuting option. The Puget sound study found that telecommuters emitted about 50% less $NO_X$ and particulate matter on days that they utilized a telecommuting center and that their CO and HC levels and number of cold starts were unaffected. [23] The Texas study reported a substantial decrease in CO, HC and $NO_X$ emissions on days that telecommuters worked at home.

The DOT study reports that telecommuting not only reduces the length of the average trip it also reduces the total number of trips. This results in a 0.23% reduction in NOx, a 0.31% reduction in HC, and a 0.36% reduction in CO emissions. [24] We have to point out that these numbers are on a *national* level. The DOT asserts out that the percentage reduction in emissions could be many times greater than these numbers reflect in localities with extreme congestion and air quality problems.

**Cost**

The cost of telecommuting appears to be minimal as long as telecommuters already have the necessary equipment. In fact many studies report an increase in productivity from workers who telecommute. [21] [22] [24] [26] Thus, employers may be more willing to participate and invest in telecommuting projects than they are in van-pooling and other employer based TDMs.

In spite of telecommuting's harmless appearance, the DOT study reports many *potential* problems that telecommuting may engender. [24] There is no hard evidence that any of these concerns will actually be a problem, but they do merit our attention. The concerns are as follows:

1) Telecommuting may induce people to move even further away from their work, thus exacerbating the "urban sprawl" phenomena.
2) Telecommuting may make van and car pools harder to arrange and thus lead to a higher percentage of single occupancy vehicles.
3) Telecommuting may stimulate "latent" demand and thus have little or no effect on congestion.
4) Telecommuters may switch to "gas-guzzling" cars with higher emissions.
5) The number of engine starts (hot and cold) may increase, thus leading to higher emissions.

While home-based telecommuting requires very little in terms of capital outlays basically a good computer and modem), enter-based telecommuting does require a significant investment. It is unclear as to whether employers are willing to establish these centers. [23]

**Conclusions**

Telecommuting is very effective at reducing the VMTs of individuals who actually telecommute. It is unclear how this will affect total VMTs and thus congestion and air quality. Since telecommuting is an inexpensive and politically feasible strategy a governmentally sponsored telecommuting project would appear advisable. Any such project *must* be voluntary since the feasibility of telecommuting depends on the situation of individual employers and employees.

Potential governmentally sponsored projects include simple information campaigns touting the increase in productivity associated with telecommuting as well as its traffic abatement effect. More ambitious projects include the subsidization of capital (including ISDN lines) involved in telecommuting for businesses with a substantial number of telecommuters.

It should be noted that the imposition of other TDMs (congestion pricing, ride-sharing, parking restrictions, etc.) on employers or employees will increase the demand for telecommuting. Thus, the imposition of other TDMs could be more effective if linked to some form of telecommuting project.

# Employer Based TDM Measures: Flexible Work Scheduling

**Description**

Flexible work scheduling may vary the hours or days that employees arrive at the work site. The desired effect is to spread the demand for travel over a wider band of time so that existing transportation systems can accommodate more commuters without additional investment in peak capacity.

> *Staggered Work Hours:* Staggered hours assign different work times to different work groups. Spacing arrivals at specified intervals before and after conventional work hours allows workers to travel at times when traffic moves more freely and more seats are available on transit. Staggered hours work well for assembly-line operations and back office operations where commencement and termination of work shifts can be easily controlled by the employer .
>
> *Flex-time:* Flex-time is a scheduling practice that allows individual employees to choose their own schedules within company set guidelines. Most flex-time arrangements allow employees to begin work as early as 7 a.m. or as late as 9:30 a.m. and many allow workers to vary their arrival times from day to day. Flex-time works well for office workers who work independently and can exercise a certain amount of discretion over the scheduling of their work.
>
> *Compressed Work Week:* Four-day work weeks allow employees to complete 40 hours of work in four 10-hour days. The system is often called 4-40. Four-forty systems have a double impact on travel to work: one day of commuting is eliminated each week; and the early arrivals and late departures built into the ten-hour days mean employees travel before and after the rush hour peaks.
> ~ *A Toolbox for Alleviating Traffic Congestion* [27]

**Effectiveness**

Staggered work hours may relieve congestion by allowing employees to avoid the worst periods of traffic congestion and transit crowding. However, a Honolulu staggered work hours demonstration project reported mixed results. Commuters that left early benefited from a decrease in travel time of about 10 percent. Commuters that left later in the morning experienced *increases* in travel time. Therefore the net effect on congestion is uncertain.[28]

Flex-time scheduling gives employees more flexibility in start times. After flex-time is introduced, more employees usually begin to carpool and use transit. Estimates are that SOV commuting may be reduced by 3 to 10 percent.[27],[29] Compressed work weeks eliminate work related VMTs. The four/forty program reduces participants weekly VMT by 20 percent. However, this reduction in VMT is likely to be offset somewhat by additional trips taken on the day off.

**Cost**

Variable work-hour programs are low in cost to the employer. Some employers report increased productivity from the participating employees. Employees that the program now allows to more conveniently use alternative transportation will realize significant cost savings.

**Conclusions**

Flexible work scheduling can be an effective strategy to facilitate ridesharing and reduce VMTs to the work site. The programs are low in cost to implement and provide additional benefits to the employer and commuters.

# Employer Based TDM Measures: Proximate Commuting

**Description**

"Proximate commuting" is based on the premise that a substantial amount of long distance commuting is unnecessary and undesirable for many commuters. Some of this commuting can be prevented or significantly reduced at multi-site employer locations through more deliberate efforts to match new and existing employees to work sites closer to their homes. The desired effect is to reduce the commute distance for some commuters so that congestion is reduced even if the commuters elect to drive alone to work. Proximate commuting, created and developed by Mullins & Associates, Inc., was demonstrated in a fifteen-month project in the state of Washington. [30]

**Effectiveness**

In Washington State approximately 40 to 45 percent of employees work for multi-site employers. Less than 20 percent of the employees involved in the demonstration project worked at the site closest to their homes. The results at the test sites indicated a 17 percent enrollment rate. Those that participated in the project reduced their VMTs by an average of 65 percent. The total VMT for all eligible employees were reduced 17 percent. [30]

**Cost**

Proximate commuting affords the participating employees considerable cost savings by way of reduced commuting expenses. The cost of administering the program is relatively low as compared to other TDM measures. Performance-based tax credits could be made available to entice employers to establish proximate commuting programs and to offset initial setup costs. Credits would have a larger effect if they are linked directly to commute miles reduced.

**Conclusions**

Removing a major portion of the commute trip by reducing the distance traveled is an inexpensive method to reduce peak hour VMTs without requiring commuters to give up their automobiles. Banks, chain stores, and other businesses that have multiple sites are good candidates for this type of program.

# Regional TDM Program Measures: Congestion Pricing

**Description**

Congestion pricing refers to placing a variable toll on a road, or system of roads. The level of the toll depends on the amount of congestion on the road: the more congestion the higher the toll. In theory, such a system would operate best with a toll that changes continuously as the level of congestion changes. In practice, much more simple pricing schemes are used. A high toll is set for the rush hours and a lower toll is set for all other times.

Each driver on a road imposes some time or convenience cost on all the other drivers on that road (we all enjoy driving on an empty road much more than on a crowded road). When roads are relatively congested each car entering the road imposes a higher cost on the other cars than when roads are relatively uncongested. The cost the individual driver imposes on the other drivers is greater than the cost the individual bears himself. Modeling done for the Minnesota DOT indicates that this cost differential is as much as $1.5 million per morning rush hour in the Twin Cities area.[39] Through congestion pricing the price individuals pay for the use of the roads can actually reflect the cost they impose on other drivers. [31]

From a policy perspective, the rationale for congestion pricing is also very simple. Higher tolls during the rush hours will induce people to travel at other times or use alternative methods of transportation. Thus, rush hour congestion will be mitigated.

From a technical perspective congestion pricing is highly feasible. A variety of technologies exist which could be used to conveniently and economically collect variable tolls.

**Effectiveness**

Although the transportation literature is nearly unanimous in its praise of congestion pricing, the technique has only been implemented on a large scale in the city-state of Singapore. The downtown business district of Singapore is completely cordoned off. Entry into the downtown area, or Restricted Zone (RZ), by car is virtually impossible without being observed by personnel in monitoring posts. During the morning and evening rush hours the toll for entry into the RZ with a private car is about $2 per day. The toll is collected through the sale of RZ area licenses that must be displayed by any car entering the RZ during the rush hours. Entry into the RZ is unrestricted during the rest of the day and night. [32]

Singapore's congestion pricing scheme has been highly effective at reducing congestion in the downtown area. When the scheme was first initiated in 1975 (only for the morning rush hour) inbound traffic to the RZ decreased by 44%, from 74,000 to 41,500 cars. By 1989 inbound traffic had increased to only 70% of its 1975 level, in spite of a 30% increase in employment in the RZ and a 77% increase in the total vehicle population. In 1989 evening rush hours began to be tolled, this resulted in a further 44% reduction in inbound vehicles (per-day). [32]

One reason cited for the great success of Singapore's scheme is its close coordination with other traffic demand management measures. Singapore's commuters were given ample and convenient alternatives to their SOVs. Currently about 70% of RZ commuters use some form of public transport. [32]

Other studies concur with the reductions in rush hour traffic reported above. [33], [34], [35], [36] Also, a significant reduction in air pollution is reported. [34]

In spite of the rosy outcome for Singapore in terms of the reduction in vehicles entering the RZ, upon closer inspection their road pricing scheme is not without problems. 44% of RZ commuters reported an *increase* in travel time as a result of congestion pricing. Also, studies using a variety of statistical models indicate that the net welfare of Singapore's society has declined as a result of congestion pricing. [33] However, these studies did not include the benefit Singapore's citizens receive from cleaner air.

France and Norway employ congestion pricing as well, but in a much more limited way than Singapore. In France, congestion pricing was instituted in 1992 on a six lane highway connecting Paris to Lille. Severe traffic jams often formed on this road on weekend afternoons due to "holiday" travel. Tolls ranging from $2 to $10 were imposed on weekend afternoons, depending on distance traveled. This resulted in a 10% decrease in peak period travel, almost all of which was shifted to off-peak period travel.[34] Norway's congestion pricing policy is designed primarily to raise revenue, not to decrease traffic volume. Thus, congestion pricing has had little effect on traffic levels in Norwegian cities. [34], [36] Also, the lack of effective public transportation in Norway is cited as a reason for congestion pricing's failure to significantly impact traffic there. [36]

The Los Angeles International Airport (LAX) employs a limited congestion pricing scheme which is apparently effective. At LAX there are about 500 ground commercial carriers (taxis, shuttle vans, etc.) operating some 5,500 vehicles. Prior to 1989 these vehicles were assessed a tax per airport entrance based on an honor system. Since 1990 an automatic vehicle identification (AVI) system has been used to collect these taxes. Every commercial vehicle operating at LAX must carry an electronic "tag" that is programmed to uniquely identify that vehicle. Antennas placed around the airport relay information from the tags to a computer that keeps track of how many times each vehicle enters the airport. Variable fees are assessed depending on the type of vehicle and on how many "loops" a vehicle makes around the airport. Since the AVI system was installed revenue collection has increased 250% and congestion has been reduced by 20%. [37]

During the 1970's a variety of congestion pricing schemes were studied in the US, none were actually implemented. [38] The general conclusion of these studies was that peak period tolls of between $2 and $3 would reduce peak period traffic by about 15-30% and reduce round trip commute times by ten to fifteen minutes per commuter. [31], [34]

Recent theoretical work on congestion pricing comes to similar conclusions about reductions in peak period congestion. However, overall welfare is shown to diminish due to congestion pricing since the value of the time commuters save due to reduced congestion is less than the value of the toll they pay. This problem is alleviated somewhat if the revenue collected from the scheme is redistributed to the commuters. [39] It should be pointed out that these welfare calculations are based on time savings and do not account for the benefits commuters receive from cleaner air.

Studies of congestion pricing that have no real data to rely on are all somewhat suspect. The reason for this is that researchers know almost nothing about how much travelers are willing to pay in tolls. [39] Results of these studies tend to depend heavily on their initial assumptions, suggesting that understanding *local* conditions is critical to implementing an optimal congestion pricing scheme. [40]

**Cost**

Implementing a congestion pricing scheme would be surprisingly inexpensive. Electronic toll collection (ETC) systems are in place and operational in many US cities. ETC systems cut out the major cost of toll collection: labor. An ETC system covering a wide metropolitan area is expected to cost less than $100 million and generate between five and seven times that amount in revenue. Systems covering specific locations or roads can be much less expensive and have similar revenue-cost multiples. [41] In general, the technology necessary for an ETC based congestion pricing scheme is considered to be reliable and is relatively inexpensive. [42]

The specific cost a congestion pricing system would impose on individual travelers is uncertain. However, the above discussion does indicate that the costs born by travelers would be very significant. On the other hand, congestion fees paid by motorists could generate a substantial cash flow for the entity operating the system.

**Conclusions**

Congestion pricing is a technically feasible way to significantly reduce congestion. In fact, *any* desired reduction in congestion could be achieved by setting a high enough toll. Congestion pricing's success does depend on there being attractive alternatives to the SOV.

Any attempt at congestion pricing must be designed with the specifics of the priced area in mind. The sprawling nature and wide surface streets of the Phoenix metropolitan area present some problems. There simply is no central business district to cordon off in Phoenix, thus the approach used in Singapore and LAX may not be feasible here. Also, the many wide surface streets may make tolling only freeways a problem. Commuters could avoid the toll simply by moving to surface streets, perhaps making congestion worse.

So far there are no major congestion pricing schemes operating in the US. This is in spite of the availability of federal funds for such projects through the FHWA. [43] The reason for this is twofold: There are no interest groups who stand to gain from a congestion pricing scheme, thus no one lobbies for it. [44] More importantly, the idea is not popular with drivers.

Public opposition to congestion pricing is well documented. [45], [46] Bad public relations are credited with scuttling congestion pricing projects from San Francisco to Hong Kong. [47], [48] In the case of San Francisco the failure to pass enabling legislation scuttled the congestion pricing project. It must be emphasized that good public relations are a *key* factor in the implementation of congestion pricing projects.

One interesting proposal to get around public opposition is to "shoehorn" congestion pricing into the transportation system by tolling only HOV lanes. During rush hours, HOV lanes would be free for vehicles with three or more occupants, while vehicles with less than three occupants would be assessed a toll. In effect, the low occupancy vehicles are given the chance to "buy into" the HOV lanes. [49] This proposal is technically feasible, and perhaps politically feasible as well, but its effect on congestion and air pollution would be more limited than a comprehensive area-wide congestion pricing scheme.

# Regional TDM Measures: HOV Preferential Lanes

## Description

There are several types of HOV facilities that can be implemented, including:

> *Exclusive HOV Facility, Separate Right of Way.* A Roadway or lane(s) developed in a separate right-of-way and designated for the exclusive use of high-occupancy vehicles.
>
> *Exclusive HOV Facility, Freeway Right of Way.* Roadways or lanes built within the freeway right-of-way that are physically separated from the other freeway lanes and are designated for the exclusive use of high-occupancy vehicles during at least portions of the day.
>
> *Concurrent Flow Lane.* A freeway lane in the peak-direction of travel (commonly the inside lane), not physically separated from the other general traffic lanes, and designated for the exclusive use by high-occupancy vehicles (usually buses, vanpools and carpools) during at least portions of the day.
>
> *Contraflow Lane.* A freeway lane (commonly the inside lane) located in the *off-peak direction* of travel designated for exclusive use by high-occupancy vehicles (usually buses only or buses and vanpools) traveling in the peak direction during at least portions of the day. The lane is typically separated from the off-peak direction travel lanes by plastic posts or pylons.

~*A Toolbox for Alleviating Traffic Congestion* [27]

HOV facilities are designed to offer incentives to encourage commuters to use buses, vanpools and carpools. Commuters can realize significant time savings from facilities that are only for HOV use. During periods of peak travel these lanes are less congested and have a considerably improved traffic flow over standard lanes.

## Effectiveness

The implementation of HOV facilities increases the people-moving capacity of the existing highway systems. If an existing lane is converted to HOV use, commuters on the remaining lanes will experience additional delay of about 12 percent. If the HOV lane is added to the existing highway, then all lanes will have increased traffic flow. Commuters using the facility typically benefit from reduced travel times of about 6 percent [27].

It is estimated that freeways carry approximately 30 percent of all traffic and that a system of HOV lanes will typically reduce the number of vehicles traveled on them by five percent [50]. This implies that an HOV system would reduce total VMT by about 1.5 percent.

Phoenix has planned for a system of 40 miles of HOV lanes. About 30 miles are presently operational. An evaluation study of Phoenix HOV facilities found that the HOV lanes are utilized by less than one third of all HOV travel. In addition, the standard lanes were found to carry more people per hour than the HOV access lanes. What this means is that at current low utilization rates, the HOV lanes in Phoenix actually increase traffic congestion over what it otherwise would be if the HOV lane were a standard traffic lane. On the other hand, freeways with HOV lanes were found to have higher automobile occupancy rates than freeways without HOV lanes. So, the person flow rate of HOV lanes could increase significantly if there were more carpools and express bus service using the HOV lanes. [51]

HOV facilities may have the effect of increasing the use of other forms of alternative transportation such as bus transit and park-and-ride lots [52],[53],[54]. Increased utilization of these services increases their cost-effectiveness.

**Cost**

The costs of HOV facilities vary greatly depending upon the type of facility implemented. Converting existing lanes for HOV use may have costs in the thousands, while separate facilities may cost up to $5 million per lane-mile. More complex facilities can run higher. For example, the city of Houston has planned for a 96 mile system of HOV transitways facilities at a cost of almost $600 million. Currently, they have 37 miles of the system operational after spending only $132 million. Adding additional facilities to the Houston system will require increasing expenditures per mile of service.

**Conclusions**

HOV facilities provide additional capacity for growing transportation system needs while providing incentives for commuters to choose alternatives to SOV travel. As demand for transportation grows, HOV facilities may become more effective for encouraging HOV travel.

# Regional TDM Measures: Park-and-Ride Facilities

## Description

Park-and ride facilities are designed to provide commuters a common location to change from a single occupancy vehicle to a mode of high occupancy travel. Park-and-ride lots provide parking spaces for automobiles along bus and rail lines. Also, they serve as meeting places for car and vanpools. The lots may be designated exclusively for use for these purposes or may be located within existing parking lots of shopping centers, churches or schools. Facilities may also be provided for securing bicycles.

## Effectiveness

Several factors have been identified that contribute to high use of park-and-ride lots. Among those cited in the literature are:

1. Existence of a well-defined travel corridor,
2. Size of population within easy access of the site,
3. Availability of transit at the site,
4. Significance of savings over automobile commute cost,
5. Distance from the site to the employment centers,
6. Availability of high-occupancy vehicle lanes
7. Quality of access to and from the site, and
8. Degree of security at the site. [55], [56]

Sites that lack one or more of these characteristics may not receive high rates of utilization.

Phoenix currently has a park-and-ride system of 61 lots, 3 of which are transit centers owned and maintained by the transit authority. The remaining 58 lots have been negotiated for park-and-ride use with the owners of the properties. Two of the lots are for car and vanpool meetings only, while the remainder are connected to bus lines. Utilization rates of the facilities range from zero to over 100 percent of capacity. The system provides a total of 2546 parking spaces. Approximately 600 of these spaces are utilized daily on average, for a rate of about 23 percent. The transit centers have utilization rates of almost 50 percent and account for 10 percent of the available spaces..

**Cost**

The chief benefit for commuters that utilize park-and-ride facilities most often cite is monetary. A Seattle study found that the park-and-ride lot user realized a savings of $1.48, or 22.9 percent per trip.[57] This study also found that the introduction of park and ride lots increased transit ridership 77 percent, which had the effect of reducing transit costs per rider trip by 5 percent. The net result was that $0.61 was spent per park-and-ride person trip, hence the system was found to be cost-effective.

The Phoenix system relies heavily on the shared-use facilities. A benefit of this is that there is no cost to acquire or maintain these sites. The only agency expense required is involved with making their existence known to the public. The agency-owned transit centers have costs associated with acquisition and maintenance.

**Conclusions**

Strategically placed park-and-ride facilities with high rates of utilization can result in increased transit use. There are several factors that are key to the success of attracting commuters to a particular lot, as outlined above. Among others listed is the existence of transit service to the site, indicating that park-and-ride facility development and transit planning may benefit when considered concurrently.

# Transportation System Improvements: Public Transit

## Description

Without an alternative to the SOV no TDM measure will be effective at reducing congestion. Whether current public transit systems are the most effective alternative to the SOV is open to question.

Public transit's effect on air pollution and congestion is questionable. A 1985 GAO study concluded that public transit has had negligible impacts on energy conservation, air pollution, and traffic congestion. [58] Low density land use patterns and the dispersed trip origins and destinations that accompany them are credited with public transit's failure to reduce congestion. [59]

Research conducted in Texas implies that studies (including the ones cited above) which rely on national statistics may not tell the full story. The Texas researchers concluded that where congestion is a severe problem public transit can have a significant impact. However, in areas with a less pronounced congestion problem public transit has little effect. In Dallas and Houston, which have significant congestion problems, public transit reduced fuel consumption and travel time. In all other large Texas cities, which have significantly fewer problems with congestion, the benefits accruing from public transit were minimal. [60] Also, public transit in small Texas communities was shown to have no positive effect on traffic congestion or energy consumption. [61]

In large urban areas where congestion is a serious problem public transit appears to be beneficial, whereas in smaller urban areas this is not the case. The proliferation of small city public transit systems since the initiation of federal subsidies washes out the impact of large cities on national statistics. Therefore, statistics based on national impacts may not accurately represent the effects of public transit in large cities such as Phoenix.

Unfortunately the effect that public transportation has on congestion and air pollution has gone largely unstudied (outside of Texas). What follows is a brief review and discussion of some current proposals relevant to public transit and the potential effectiveness.

The discussion of public transit will be broken into four categories:

1. Increased Bus Service.
2. Fare-Free Bus Service.
3. Privatization.
4. Rail.

## Increased Bus Service

The sources cited above imply that increasing bus service will only be effective if it is targeted at an excessively congested area. Thus, if *specific* bus routes can be identified that correspond with highly congested corridors, then adding bus service may be very effective. Evidence from Philadelphia indicates that drastic differences in ridership can result from adding capacity to routes during peak periods. [62]

Currently, we are unable to find any research specific to the Tucson and Phoenix bus systems. Studying the performance of these systems on a route by route basis while taking account of congestion levels around each route could be very beneficial. It may be the case that simply rearranging the routes will reduce congestion at almost no cost.

One problem with the Phoenix bus fleet is its age. The average Phoenix bus is over nine years old and there are many buses more than twenty years old. Older diesel engines are very high emitters of air pollutants, in terms of grams per mile they emit almost 75% more pollutants then the average vehicle fleet. New diesel engines are much cleaner. In fact, new diesel buses emit less pollutants than natural gas buses and cost $40,000 less per bus. In spite of this, Arizona law requires that any new buses purchased must be natural gas. [63]

**Fare Free Bus System**

Drastic reductions in, or outright elimination of, bus fares has been suggested as an easy way to increase ridership. The rationale is that since collected fares account for such a small amount of operating costs, eliminating them will not affect the financial status of the system very much. Since the demand for bus service is inelastic ( the percentage increase in ridership will be less than the percentage decrease in fares) revenue collected will fall. Also, costs are expected to increase significantly and quality of service is expected to decline appreciably. [64], [65] As an illustration, the 100% fare subsidies given to state workers in Phoenix have resulted in only a 25% increase in the number of state workers that use public transit.

Drastic fare reductions seem like a bad idea for three reasons: First, the rationale is perverse. Essentially, the argument is that since buses are not cost effective they might as well be free. Second, the increase in ridership causes an increase in cost and reduction in the quality of service. Third and most important, there is no evidence that the small increase in ridership will have a significant impact on congestion or air pollution.

**Privatization**

Increasing the private sector's involvement in the provision of transportation appears to have the potential to reduce congestion and increase air quality. A large body of literature exists which asserts that publicly owned transit systems are more prone to respond to political pressure than to transportation needs. Thus, deregulating local transportation markets could both save money and increase the service available to the public. [66] Just as deregulation on the national level for trucking and airlines has been highly successful, deregulating local transportation markets promises to have a substantial positive impact on transportation service. The granting of exclusive monopolies to bus and taxi operations is seen as a hindrance to efficiency. [67] The subsidization of bus service and of parking is seen as a principle reason for the failure of for-profit van service in suburban Los Angeles. [68]

In both theory and practice the private provision of public transportation is shown to be a viable option. A recent study commissioned by the Reason Foundation concluded that privately operated shuttle vans can operate at a total cost 93% less than rail and 67% less than conventional bus service. Shuttle vans also consume dramatically less energy than either buses or rail on a passenger-mile basis. Private van service is also said to be a viable for-profit business and its potential can only increase as governments place more restrictions on SOVs. The study points out that the implementation of shuttle van service at LAX alone has resulted in a 65.84 ton estimated reduction in annual emissions. [69]

Mathematical modeling of urban transportation indicates that for-profit van and bus service can work. In the *total* absence of government intervention it is found that private firms could provide effective service along routes greater than eight miles and along corridors with total volume of 2,000 or more passengers per day. The fares such private firms would charge would be slightly higher than current subsidized bus fares. However, the level of service that the private firms would provide would greatly exceed that of current subsidized bus services. [70]

There is also plenty of empirical evidence to support the viability of privatization. Private transit providers prosper in many foreign cities, including Buenos Aires, Manila and several Israeli cities, without any subsidies. These providers typically operate small individually owned vehicles organized in route associations. [71], [72] In the US highly successful van services have operated where legal and regulatory loopholes allow them. A discrepancy between state and local laws created a loophole that allowed jitney service to flourish in Miami during the early 1990s. The jitneys reportedly had *cheaper* fares than the county bus system and offered more flexible service. [73] Private operators in Chicago took advantage of regulatory loopholes and a 100% public transit rate hike in 1981 and founded successful "subscription bus" service companies. These companies sell transportation service on a month to month basis and in 1984 carried 5,000 passengers daily. Low fares and flexible schedules are cited as the main appeal of these buses. [75] In Pittsburgh illegal jitneys are known to operate successfully. Although illegal, these jitneys are said to offer low fares and high quality service. [71]

Of course the privatization of public transit raises equity issues. Such a policy may be perceived as hurting low income transit riders. This is a legitimate concern but it may have a simple answer. Transportation vouchers could be issued to low income transit users in the same way that food stamps are issued now.

**Rail**

As is the case with bus service, rail may reduce congestion along specific high density and highly congested corridors. Given the suburban nature of the Phoenix and Tucson areas this potential may not be large. The low densities and dispersed trip origins typical of suburban cities are cited as principle reasons for the ineffectiveness of rail transport in the sun belt. [75], [76] A study of the Metrolink commuter rail system in Los Angeles concluded that commuter rail can not serve suburb-to-suburb routes to the same extent that it serves suburb to central business district routes. [77] Given the high degree of suburb-to-suburb travel in the Phoenix and Tucson areas it is unlikely that a rail system could effectively serve area residents.

The US DOT reports many examples of rail systems that have had little impact on congestion. The Washington DC rail system reduces emissions by 1% and SOV trips have been steadily increasing there in spite of the existence of the rail option. An $11 billion investment in rail and other capital improvements in San Francisco has resulted in less than a 1% reduction in emissions. A twenty mile extension of San Diego's light rail system is expected to reduce emissions by about 0.5%. An extensive rail system in Los Angeles is expected to reduce emissions by 1% to 3%. [78]

We can get an idea of the potential cost and air quality impact that introducing an extensive rail transit in Phoenix would entail by evaluating the 1988 ValTrans proposal. [79] In 1988, the Valley Metro Regional Public Transportation Authority (RPTA) published a draft report detailing ValTrans, a proposed rail and expanded bus network that was to be completed by the year 2020. In 1988, the RPTA estimated that the ValTrans system was expected to cost $9.6 billion over 30 years in 1988 dollars, which translates into $12.7 billion in 1996 dollars. It should be noted that initial estimates of rail systems costs usually dramatically underestimate the true final cost. [75]

ValTrans was to include:

- 103 miles of new light rail lines.
- Use of existing Southern Pacific railroad lines.
- 29 miles of busways on valley freeways.
- Improvements in existing buses.
- A bus fleet of 1,300 and 59 million miles of bus service.
- A timed transfer system.
- Paratransit or dial-a-ride services for areas with low population density.
- Inter-city rural bus service.
- A regional ridesharing program.

The ValTrans plan was more than just a rail transit system. Nevertheless, since light rail transit, on a full cost basis, is more expensive per passenger mile than bus service, the combined rail and bus costs of the ValTrans proposal do not overstate the prospective per passenger costs of a rail-only option. Clearly, a smaller rail transit proposal would cost less and have less impact on air pollution.

Currently, Maricopa County Association of Governments Transportation Planning Office (MAGTPO) estimates that vehicle miles traveled (VMTs) in the Phoenix area are about 60 million per weekday. The MAGTPO's forecast for the year 2020 is that weekday VMTs will reach 95 million, a 58% increase. This increase in VMTs is expected to be offset by the fact that vehicles will be emitting fewer pollutants. Thus, tons of vehicle emissions per year in 2020 are likely to be comparable to levels experienced today (assuming technological advances like the "cold start" catalytic converter or improved catalytic converter insulation [92] are introduced, emissions in 2020 would be significantly lower than they are today despite increases in traffic volume).

The RPTA estimated that there would be 189 million passenger trips (each time a person boards a bus or train it is counted as a separate "trip") per year in 2020. Assuming that each trip is 3.9 miles (currently, Phoenix Transit averages 3.9 miles per trip, cities with rail transit average "trip" lengths of similar length) gives 737 million passenger miles for ValTrans in 2020. Total VMT in 2020 is projected to amount to 31 billion. If we assume that every ValTrans passenger would be a SOV driver if ValTrans were not available, then ValTrans would have reduced automobile VMTs by 2.4%, in 2020. This is probably an unwarranted assumption, typically, the majority of rail passengers were formerly bus riders. In Los Angeles, only 10% to 15% of the passengers on the new rail transit line were formerly SOV drivers, 85% to 90% were formerly bus riders. [95]

More recently, RPTA has come forward with a more modest rail transit proposal. [91] In this proposal, there are only 20 miles of at-grade track(i.e., running on the same level with the streets) rather than 103 miles of elevated track. This substantially reduces the cost of construction. Impacts on SOV travel are also likely to be smaller. (There would also be some degree of impedence of motor vehicle traffic that had to be stopped to allow passage of the at-grade trains. The quantity of this impedence is not known and is consequently ignored in the estimates of the pollution reduction potential of this option.) Operating costs are estimated at $14.8 million per year (counting the portion covered by passenger fares, approximately $4.4 million). Capital costs are estimated at $41.8 million (counting both the 50% federal and 50% local share) per year. This puts the total cost for this rail service at $56.6 million per year. Passenger fares are expected to cover about 8% of the full cost of this rail option. RPTA expects to increase unlinked trips by 9.2 million per year and to boost unlinked trip lengths from the current level of 3.9 miles per trip to 6 miles per trip to produce a transit passenger miles of travel increase of 55.2 million per year. If we assume that all of this travel would have otherwise gone via SOV, we would multiply the 55.2 million by the 18.15 tons per 1,000,000 auto VMT emission rate to get a pollution reduction of 1002 tons per year. (This is probably excessively optimistic. Typically, the majority of rail passengers were formerly bus riders. In Los Angeles, only 10% to 15% of the passengers on the new rail transit "Blue Line" were formerly SOV drivers, 85% to 90% were formerly bus riders. [95]) Dividing this tonnage into the $56.6 million of additional transit cost yields a price of $56,487 per ton.

## Conclusions

There are many policies concerning public transit that governments can pursue. The literature provides no evidence to support the assertion that any of these types of policies will have a significant impact on air quality.

# Transportation System Improvements: Intelligent Transportation Systems

Intelligent transportation systems (ITS) are computer controlled systems that are used to monitor and manage traffic. ITS covers a broad range of systems that can be used to increase the efficiency of surface streets, highways, public transit, and incident management. The following options will be discussed in turn:

- Traffic Signal Timing Optimization
- Freeway Management Systems
- Incident Management Programs
- Multimodal Traveler Information Systems

## Traffic Signal Timing Optimization

### Description

Optimal signal timing requires the design and implementation of a set of coordinated traffic signal operation plans that will result in reduced stops, fewer delays and less fuel consumption for motorists. Several timing plans are normally required for an intersection or a system to match the various traffic-volume levels encountered at different times of the day, month or year. It has been estimated that one-fifth of the total US oil consumption is used by vehicles traveling in urban areas through signalized intersections. In street networks with poorly timed traffic signals, the fuel consumed by vehicles stopping and idling at traffic signals accounts for approximately 40 percent of network-wide vehicular fuel consumption. Improving traffic-signal timing will improve the quality of traffic flow 24 hours per day, 7 days per week with no sacrifice on the part of the individual.[80]

A synchronization program would include retiming of coordinated traffic signals and replacing outdated equipment of non-coordinated signals. Data collection is the major and key task in successful implementation of a signal timing optimization project. Computer models are used to determine the optimal timing plans. There are a number of software programs available for signal timing optimization. The available timing systems range in sophistication from fixed-time plans for individual intersections to systems that collect and analyze traffic data in real-time and automatically adjust the timing pattern according to demand conditions. Updating of optimal timing plans should be done periodically to reflect changing traffic demands [81].

### Effectiveness

The reported benefits of signal timing projects have been substantial. Many states have reported significant benefits per dollar of expenditure in their synchronization programs. The findings of three states' studies are outlined below. Each study reports high benefit/cost ratios. However, these ratios are not easily comparable due to the different methods and values used in calculating benefits. In most studies, the fuel savings alone were calculated to exceed the cost of implementing the program.

**California**

California's Fuel Efficient Traffic Signal Management (FETSIM) Program completed in 1991 reported reduction of fuel consumption by 8.1 percent, while the number of stops and delays declined by 14 percent [81]. The program involved retiming of 9,000 signalized intersections. The program did not allow for the upgrade of older, outdated equipment. Therefore, the results reflect only the retiming of signals already within a coordinated system. The first year benefit to cost ratio was 16 to 1.

**Texas**

Texas's Traffic Light Synchronization II (TLS II) Program initiated in April, 1991, and completed in February, 1995, funded the retiming of 1348 signals. A follow-up study reported reduced fuel consumption, and fewer delays and stops by 13.5, 29.6, and 11.5 percent, respectively [82]. Estimated annual fuel savings per intersection is 15,429 gallons. TLS II included funding for updating older equipment while FETSIM only allowed for the retiming of already coordinated signals. TLS II generally reported large improvements when coordinating previously uncoordinated systems. In addition, TLS II results reflect an average of 43 cities ranging in population of under 50,000 to over 200,000. Cities of greater than 200,000 reported the greatest benefits from the program. The calculated benefit/cost for TLS II was 32 to 1.

**Illinois**

Illinois's Department of Transportation initiated a statewide Signal Coordination and Timing (SCAT) project. The objectives of the SCAT project were to determine needs, opportunities, costs, and benefits of signal operation improvements in Illinois and to develop a statewide program for implementing these improvements [83]. The most positive benefit/cost ratios were determined to be possible from improved timing of isolated signals, coordination with other signals, and use of a late-night flash. The calculated ratios were 63, 16, and 6 dollars of benefit, respectively, received by motorists for each dollar of expenditure. These estimates are based on the potential benefit of including all signals in the state in the program. The Texas and California programs targeted signals and systems that would provide the most benefit. Therefore, an equally focused program in Illinois would be expected to realize higher benefit/cost ratios.

## Cost

Costs of signal timing programs can vary greatly. All timing programs must include data collection, data processing, timing plan development, implementation, and field evaluation. The substantive differences in costs will depend on any new equipment purchases and installations. For example, FETSIM only allowed  for the retiming of existing coordinated signals. The average cost per intersection was $1,500. TLS II allowed for the replacement of outdated equipment that allowed previously unconnected signal to be include in a system. The resulting average cost per intersection was $5,700. The cost to re-time a signal that is within a coordinated system should fall between $500 and $2000 [81]. The replacement or updating of outdated equipment will run between $5,000 and $9,000 per intersection [84].

## Conclusions

Signal timing optimization projects are highly cost effective. Studies estimate such projects provide 20 to 30 dollars in benefits for each dollar expended.. Much of this benefit comes from reduced fuel consumption, which should translate directly to reduced automobile emissions.

The state of the art in signal timing systems are known as second-and third-generation control systems. These systems generate timing plans while on-line and operate by automatically collecting data, calculating the signal changes and implementing the changes in real-time. The installation of numerous detectors is necessary in order to have sufficient data to calculate the timing plans. Installation is expensive, and has only been recently begun in the US.

Third-generation control systems have been developed that may offer improvements over the second-generation systems. Preliminary results from a system being developed at the University of Arizona indicate that delays can be reduced by an additional 10 to 25 percent over the systems currently available. The cost for a system of this type is estimated to be about 50 thousand dollars per intersection.

Phoenix and Tucson currently have different traffic signal control systems. The Tucson system is a more advanced second-generation type system than the Phoenix system. Recently Phoenix has begun to upgrade areas of the system to be comparable with the Tucson system. Impact estimates have only been calculated for the Phoenix system as it has the most room for improvement. However, there is technology available that could significantly improve upon both the existing Tucson and the new Phoenix systems.

## Freeway Management Systems

### Description

Freeway management systems fall into several categories:

1. Ramp metering.
2. Variable speed limit signs.
3. Corridor Control Strategies.
4. Real-time changeable message signs for traffic information.
5. Radio transmission of traffic information.
6. On-board navigation systems.
7. Electronic route planning and information systems: link computer algorithms to highway network data bases, accounting for real-time traffic conditions.
8. Externally linked route guidance systems: provide real-time traffic information and suggest alternative routes.

### Effectiveness

Freeway management systems have been found to have substantial benefits. The US Department of Transportation reports the following benefits from freeway management systems:

a. Average travel time reductions of 20% - 48%.
b. Average travel speed increases of 16% - 63%.
c. Freeway capacity increases of 17% - 25%.
d. Accident rate reductions of 15% - 50%.
e. Fuel consumption reductions of 41%.
d. Substantial reductions in emissions. [85]

The US DOT's numbers are somewhat misleading. Their numbers are calculated under the assumption that total VMTs do not change as a result of the freeway management system. Since freeway capacity is increased by freeway management systems the total VMTs are likely to increase. Such an increase in VMTs will partially offset the emission reductions resulting from freeway management systems.

### Cost

There is little data available on the costs of freeway management systems. The little information available on the subject indicates that freeway management systems are cost effective relative to expanding existing highways. The US DOT reports that the implementation of a freeway management system on a four lane highway will increase capacity by about half that of an additional lane at about 1/8 the cost of an additional lane. [85]

The costs of freeway management systems can vary greatly across localities. Costs can range from a few hundred thousand dollars to tens of millions of dollars. Costs vary depending on the following factors:

1) *Infrastructure already in place.* In locations that already have an advanced telecommunication infrastructure implementing an ITS program requires minimal capital expenditures.
2) *Choice of algorithm.* If an existing computer algorithm can be “fitted” to a particular freeway system costs are much lower than if a new algorithm must be created from scratch.
3) *Federal participation.* Federal money is available for ITS programs to offset some of the cost incurred by states and localities.

**Conclusions**

Freeway management systems may have a significant effect on air quality. Further study is required to estimate the air quality impacts of a freeway management system. Additional information about the systems and the local congestion conditions in Arizona are necessary before we can attempt to quantify the potential impacts.

## Incident Management Programs

### Description

Incident management systems range from simple systems that allow motorists to report accidents or traffic delays via cellular phones to advanced video monitoring systems that keep officials constantly informed about current road conditions.

### Effectiveness

Since 50%-60% of all traffic congestion is attributed to incidents, incident management is very important. [85] Advanced incident management systems have been shown to reduce incidence clearance times by up to eight minutes. Travel time can increase by 10%-42% when incident management systems are integrated into freeway management systems. [86] Also, the reduction in incident notification times due to incident management programs are projected to result in a 10% reduction in fatalities due to accidents. [85]

### Cost

Incident management systems appear to be fairly inexpensive. The US DOT estimates that an effective program can be implemented for an annual cost of $600,000.

### Conclusions

Incident management systems will reduce emissions to some degree. The impact is difficult to estimate and requires understanding of the relationship between congestion resulting from incidents and vehicle emissions. This topic has yet to be addressed in the literature. Therefore, no estimate of potential impact of this measure has been included in this study.

## Multimodal Traveler Information Systems

### Description

Multimodal Traveler Information Systems are systems that are used to inform motorists about current road conditions. These systems include variable message signs on freeways or surface streets that can continuously update motorists about road conditions ahead. Programs that allow motorists to easily "call in" problems with their cellular phones have also been successful. Radio broadcasts of highway information is another successful traveler information system. In Los Angeles 78 electronic information kiosks have been deployed in places like office lobbies and shopping plazas. These kiosks provide potential motorists with a variety of information about traffic conditions and public transit schedules. [85]

### Effectiveness

Surveys indicate that 30% to 40% of travelers frequently adjust travel patterns based on information about road congestion. [87] Thus, providing motorists with more information about congestion has the potential to reduce congestion and emissions. The US DOT reports that travel time, fuel consumption, and emissions are significantly reduced for vehicles *actually affected* by the information system. [85] Traveler information systems will only have a significant impact on emissions if enough motorists are affected by them. Whether this is possible or not is questionable. Current systems may affect less than 1% of motorists. [85]

### Cost

Traveler information systems are relatively inexpensive. The information that they convey to motorists is, for the most part, already collected by local transportation officials. Implementing a traveler information system is simply a matter of installing the hardware necessary to convey that information to motorists.

### Conclusions

Traveler information systems are inexpensive and useful. Their effect on air quality is uncertain. Estimating the effect of traveler information systems on air quality requires study of the systems effect on motorists' travel decisions.

# Appendix A: Emissions Reductions for Phoenix and Tucson

Tables A1 through A4 contain estimates of near term (within five years) emission reduction impacts in Phoenix and Tucson based on an evaluation of the congestion abatement literature and air quality models. The estimates are intended to reflect successful implementation of the measures with outcomes comparable to the more optimistic results reported in the literature. Where possible, results and costs have been estimated to reflect programs currently operational in Phoenix and Tucson. These estimates provide a starting point for comparison of the many congestion management measures available that may be considered for the purpose of improving air quality.

**Table A-1: Emissions Reductions Policies Ranked by Order of Potential Magnitude**
(near term annual impacts for Phoenix region)

| **Policy** | **Cost** | **Pollutants Removed** | | **Cost/ Ton** |
|---|---|---|---|---|
| | millions of $ | tons/year | percentage | $ per ton |
| Signal Synchronization(California model) | 13.5 | 30,163 | 8.10% | 448 |
| Congestion Pricing | 1000 | 16,422 | 4.41% | 60,894 |
| Signal Synchronization(MCDOT estimate) | 25 | 9,310 | 2.50% | 2,685 |
| Signal Synchronization(Texas model) | 8.55 | 8,461 | 2.27% | 1,011 |
| Parking and Transportation Allowance | 110 | 6,594 | 1.77% | 16,682 |
| HOV Lanes | 32 | 5,218 | 1.40% | 6,133 |
| Compressed Work Week | nil | 5,218 | 1.40% | nil |
| Parking Management | 58 | 5,181 | 1.39% | 11,195 |
| Telecommuting Half Time | 3.446 | 4,227 | 1.14% | 815 |
| Maricopa County TDM Program | 1.8 | 3,438 | 0.92% | 524 |
| Transportation Allowance Program | 18 | 3,297 | 0.89% | 5,460 |
| Flex Time | nil | 3,061 | 0.82% | nil |
| High Bus Expansion | 144 | 3,049 | 0.82% | 47,229 |
| Natural Gas Bus Service | 74.7 | 2,304 | 0.62% | 32,422 |
| Bus Service | 66.5 | 2,077 | 0.56% | 32,017 |
| Telecommuting (1 day a week) | 3.446 | 1,691 | 0.45% | 2,038 |
| Proximate Commuting | nil | 1,629 | 0.44% | nil |
| Guaranteed Ride Home | 0.36 | 1,361 | 0.37% | 265 |
| Moderate Bus Expansion | 72 | 1,143 | 0.31% | 62,992 |
| Rail Transit(ValTrans model) | 530 | 1,089 | 0.29% | 486,685 |
| Ridematching Programs | 0.1 | 785 | 0.21% | 127 |
| Vanpooling | 0.4 | 364 | 0.10% | 1,099 |
| Rail Transit(20 mile, at grade) | 56.6 | 150 | 0.04% | 377,333 |
| Park and Ride | 0.181 | 63 | 0.02% | 2,873 |

**Table A-2: Emissions Reductions Policies Ranked by Cost-Effectiveness**
(near term annual impacts for Phoenix region)

| Policy | Cost | Pollutants Removed | | Cost/ Ton |
|---|---|---|---|---|
| | millions of $ | tons/year | percentage | $ per ton |
| Compressed Work Week | nil | 5,218 | 1.40% | nil |
| Flex Time | nil | 3,061 | 0.82% | nil |
| Proximate Commuting | nil | 1,629 | 0.44% | nil |
| Ridematching Programs | 0.1 | 785 | 0.21% | 127 |
| Guaranteed Ride Home | 0.36 | 1,361 | 0.37% | 265 |
| Signal Synchronization(California model) | 13.5 | 30,163 | 8.10% | 448 |
| Maricopa County TDM Program | 1.8 | 3,438 | 0.92% | 524 |
| Telecommuting Half Time | 3.446 | 4,227 | 1.14% | 815 |
| Signal Synchronization(Texas model) | 8.55 | 8,461 | 2.27% | 1,011 |
| Vanpooling | 0.4 | 364 | 0.10% | 1,099 |
| Telecommuting (1 day a week) | 3.446 | 1,691 | 0.45% | 2,038 |
| Signal Synchronization(MCDOT estimate) | 25 | 9,310 | 2.50% | 2,685 |
| Park and Ride | 0.181 | 63 | 0.02% | 2,873 |
| Transportation Allowance Program | 18 | 3,297 | 0.89% | 5,460 |
| HOV Lanes | 32 | 5,218 | 1.40% | 6,133 |
| Parking Management | 58 | 5,181 | 1.39% | 11,195 |
| Parking and Transportation Allowance | 110 | 6,594 | 1.77% | 16,682 |
| Bus Service | 66.5 | 2,077 | 0.56% | 32,017 |
| Natural Gas Bus Service | 74.7 | 2,304 | 0.62% | 32,422 |
| High Bus Expansion | 144 | 3,049 | 0.82% | 47,229 |
| Congestion Pricing | 1000 | 16,422 | 4.41% | 60,894 |
| Moderate Bus Expansion | 72 | 1,143 | 0.31% | 62,992 |
| Rail Transit(20 mile, at grade) | 56.6 | 150 | 0.04% | 377,333 |
| Rail Transit(ValTrans model) | 530 | 1,089 | 0.29% | 486,685 |

**Table A-3: Emissions Reductions Policies Ranked by Order of Potential Magnitude**
(near term annual impacts for Tucson region)

| Policy | Cost | Pollutants Removed | | Cost/ Ton |
|---|---|---|---|---|
| | millions of $ | tons/year | percentage | $ per ton |
| Congestion Pricing | 250 | 4141 | 4.45% | 60,372 |
| Natural Gas Bus Service | 35 | 1078 | 1.16% | 32,468 |
| Parking and Transportation Allowance | 20 | 1067 | 1.15% | 18,744 |
| Bus Service | 34 | 941 | 1.01% | 36,132 |
| Parking Management | 10.7 | 839 | 0.90% | 12,753 |
| Compressed Work Week | nil | 839 | 0.90% | nil |
| Telecommuting Half Time | 0.554 | 680 | 0.73% | 815 |
| Transportation Allowance Program | 3.4 | 534 | 0.57% | 6,367 |
| Flex Time | nil | 495 | 0.53% | nil |
| Telecommuting (1 day a week) | 0.554 | 272 | 0.29% | 2,037 |
| Guaranteed Ride Home | 0.063 | 272 | 0.29% | 232 |
| Proximate Commuting | nil | 261 | 0.28% | nil |
| Ridematching Programs | 0.1 | 127 | 0.14% | 787 |

**Table A-4: Emissions Reductions Policies Ranked by Cost-Effectiveness**
(near term annual impacts for Tucson region)

| Policy | Cost | Pollutants Removed | | Cost/ Ton |
|---|---|---|---|---|
| | millions of $ | tons/year | percentage | $ per ton |
| Compressed Work Week | nil | 839 | 0.90% | nil |
| Flex Time | nil | 495 | 0.53% | nil |
| Proximate Commuting | nil | 261 | 0.28% | nil |
| Guaranteed Ride Home | 0.063 | 272 | 0.29% | 232 |
| Ridematching Programs | 0.1 | 127 | 0.14% | 787 |
| Telecommuting Half Time | 0.554 | 680 | 0.73% | 815 |
| Telecommuting (1 day a week) | 0.554 | 272 | 0.29% | 2,037 |
| Transportation Allowance Program | 3.4 | 534 | 0.57% | 6,367 |
| Parking Management | 10.7 | 839 | 0.90% | 12,753 |
| Parking and Transportation Allowance | 20 | 1067 | 1.15% | 18,744 |
| Natural Gas Bus Service | 35 | 1078 | 1.16% | 32,468 |
| Bus Service | 34 | 941 | 1.01% | 36,132 |
| Congestion Pricing | 250 | 4141 | 4.45% | 60,372 |

# Appendix B: Notes on Estimate Calculations

Calculating the reduction in VMTs for each congestion abatement measure requires making certain assumptions. These assumptions, together with data from the census, Arizona Department of Environmental Quality and other government agencies were used to estimate each of the measures impact on congestion and corresponding air quality improvement. The analyses of the Phoenix and Tucson regions are similar, but not identical. Due to differences in the availability of information, the list of measures analyzed for Tucson was smaller.

Changing the assumptions would alter the estimated impacts of the measures. However, in many cases serious alterations in the assumptions used to calculate the impacts will not lead to a significant change in a measure's *relative* ranking, either by magnitude or cost-effectiveness.

## General Assumptions

| | *Phoenix Area* | *Tucson* |
|---|---|---|
| Total VMTs per day | 60 million | 15 million |
| Total air pollution per weekday | 1,143 tons | 286 tons |
| Total air pollution per year | 372,388 tons | 93,097 tons |
| Total Commuter Trips per day | 967,186 | 176,965 |
| Average Commuter Trip Length (one way) | 11.9 miles | 10.4 miles |
| Commuter VMTs/weekday | 23 million | 3.7 million |
| Commuter air pollution/weekday | 417 tons | 67 tons |
| SOV Commuter VMT/weekday | 17.3 million | 2.8 million |
| SOV Commuters/weekday | 728,000 | 135,000 |
| HOV Commuter VMT/weekday | 5.7 million | .9 million |
| HOV Commuters/weekday | 239,000 | 42,000 |
| VMT during peak six hours/weekday | 23 million | 5.8 million |
| Full cost to operate an automobile | 44 cents/mi. | 44 cents/mi. |

## Estimated Quantities of Pollutants in Tons

| Pollution Source | HC | CO | NO | PM10 | Total |
|---|---|---|---|---|---|
| Avg of all vehicles/1,000,000 vmt | 3.19 | 13.65 | 2.04 | .17 | 19.04 |
| Avg of all vehicles/weekday/Phoenix | 191 | 819 | 122 | 10 | 1143 |
| Avg of all vehicles/weekday/Tucson | 48 | 205 | 31 | 2 | 286 |
| Auto/1,000,000 vmt | 3.04 | 13.19 | 1.84 | .08 | 18.15 |
| Diesel/1,000,000 vmt | 3.37 | 7.96 | 7.68 | 1.82 | 20.84 |

## Regional Transportation Demand Management Program Measures

### Phoenix Transportation Demand Management Program

According to the Maricopa County Regional Trip Reduction Program Task Force 1995 Annual Report, SOV modal share is estimated to be 76 percent in 1995. This represents a 7.3 % reduction from the baseline measure of 82 % SOVs in 1989. Only a tiny fraction of those driving to work in SOVs could conceivably walk or bicycle. Consequently, it is assumed that former SOV drivers are forming carpools or taking transit. This will increase the HOV VMTs, offsetting some of the implied gains from reducing SOVs. The premise used here is that for every 1% decrease in SOVs there is a corresponding increase in HOVs formed. The ratio is such that the net reduction in commuter VMT will be only .6% of the SOV reduction. So, if SOVs decline by 7.3%, we get a 1.26 million per weekday decrease in SOV commuter VMT. The increase in HOV VMT reduces this figure to .76 million (1.26 times .6). For the Phoenix region, this per weekday VMT decrease is multiplied by 250 workdays to get a yearly figure of 189 million. At an emission rate of 18.15 tons per 1,000,000 auto VMT, we get an annual pollution reduction of 3438 tons per year.

The MAGTPO annual budget of $1.8 million has been used as an estimate the costs of implementing the TDM program. This divided by the 3438 tons of pollution reduction yields a cost of $524 per ton. This probably under estimates costs somewhat since employers incur some costs in efforts to comply with the ordinance.

## Employer-Based Trip Reduction Methods

### Ridesharing

#### *Ridematching*

It would appear from the literature that for ridematching services to be effective, sufficient incentives must exist for employees to consider ridesharing opportunities. Assume that sufficient incentives do exist, SOV modal share to be 75 percent, current rideshare (car/vanpool) modal share is 15 percent and no organized ridematching system is currently in place. The estimated impact of introducing a ridematching service might be a 5 percent increase in ridesharing, from 15 to 15.75 percent. SOV modal share would then decrease from 75 to 74.25 percent. This would represent a 1 percent decline in SOV use. For the Phoenix region, SOV VMT amounts to around 17.3 million per wekday. One percent of this is 173,000 VMT. This VMT multiplied by the commuter pollution factor of 18.15 tons per million VMT yields a 3 ton per weekday reduction in pollution. Assuming 250 workdays, this will reduce annual pollution in the region by about 785 tons. With an estimated annual cost of this program of $100,000, the per ton cost of pollution abatement becomes $127.

If a similar results could be achieved in the Tucson region, a 1% decrease in SOV VMT would amount to 28,000 per weekday. Assuming 250 workdays, we get an annual commuter VMT reduction of about 7 million. Using the 18.15 tons per 1,000,000 auto VMT emission factor, we estimate a reduction of 127 tons per year. With an estimated annual cost of $100,000, the per ton cost of pollution reduction is $787.

### *Guaranteed Ride Home*

Some survey studies report that up to ten percent of rideshare participants have reported that they would not be willing to leave their car at home without a guarantee of a ride in case of emergencies. Putting aside the problems inherent in survey data aside and taking the reported number at face value would imply that the introduction of a GRH program where one is not currently in place could increase rideshare participation by up to 11 percent. For purposes of estimated potential impacts, it has been assumed that employer-based TDMs are in effect. The pre-implementation SOV modal share is 75 percent and HOV share is 25 percent. Thus, a GRH program implementation increases HOV modal share to 27.25 percent, and decreases SOV share to 72.75 percent. If a 75% SOV modal share produces 17.3 million VMT per weekday in Phoenix, then a 72.75 percent share will yield an SOV VMT of 16.8 million. Using the .4% HOV increase per 1% SOV decrease ratio, a 500,000 VMT reduction in SOV travel is offset by a 200,000 VMT increase in HOV travel for a net reduction of 300,000 VMT per weekday. Assuming 250 workdays per year, this would imply 75 million fewer commuter VMTs for the year. Given a pollution emission factor of 18.15 tons per auto VMT, this would reduce pollutants by about 1361 tons per year.

The average cost of providing a guaranteed ride is estimated to be $50. It is estimated from the literature that 3 percent of eligible commuters will actually use the service each year. If there are 239,000 HOV commuters in the Phoenix region and 3% of them use this service once per year, the annual cost of this program would approximate $360,000. If pollution is reduced by 1361 tons per year, the cost per ton of pollution reduction would be about $265.

Applying similar assumptions in Tucson finds SOV commuter travel reduced from 2.8 million VMT per weekday to 2.7. This 100,000 decline in SOV VMT is offset by a 40,000 increase in HOV VMT for a net weekday reduction of 60,000 commuter VMT. Given 250 workdays per year, we get a total commuter VMT reduction of around 15 million. At 18.15 tons per million auto VMT, this equates to a pollution reduction of about 272 tons per year.

The average cost of providing a guaranteed ride is estimated to be $50. It is estimated from the literature that 3 percent of eligible commuters will actually use the service each year. If there are 42,000 HOV commuters in the Tucson region and 3% of them use this service once per year, the annual cost of this program would approximate $63,000. If pollution is reduced by 272 tons per year, the cost per ton of pollution reduction would be about $232.

***Parking Management***

Parking management strategies can be highly effective at reducing SOV use given that the right conditions exist. Sufficient alternatives to SOV travel and scarcity of off-site parking are neccessary to achieve the impressive reductions that have been reported in the literature. It is not likely that these conditions exist to the same degree in Phoenix as might be found in cities with higher population densities and centralized business districts. Therefore, realistic expectations of parking management techniques would be for more modest reductions in SOV use. Ideal conditions for a highly effective program are:

Employer-based TDM in effect.
SOV modal share is 75%.
No transit subsidy currently provided.
Employee parking is provided free by the employer.
Sufficient alternatives to SOV travel exist.
Off -site parking is scarce.

Theoretically, given the above conditions, any level of participation could be achieved, if the parking cash-out payment were made high enough. The payment offered is designed to encourage employees to leave their car at home and most every employee has a reservation price that would entice them to do so. Practically, the employer will only be able or willing to offer up to their perceived cash-value of the parking spot. A reasonable value might be a payment of $60 a month to employees that do not utilize SOV travel. It may not be the case that all employers in Phoenix and Tuscon will be able to offer this type of arrangement. However, financial incentives to use alternative transportation are among the most effective measures discussed in the literature. The relevent question is how many additional employees will change their modal choice when offered the cash-out option and at what price will they do so.

A reasonable estimate might be that eight additional employees of every one-hundred at a work site will choose the cash-out option when the payment is set at $60/month. This level of particpation is a 32 percent increase in non-SOV travel. A program offered to Arizona state government employees provided free bus service to employees during the summer months. The cash-value of this subsidy is about $60 per month. This program resulted in a 25 percent increase in state employee bus ridership. A cash payment year round would be expected to result in higher participation. The reduction in SOVs is estimated to be 11 percent. If the reduction in SOV VMT is 11%, we would have 1.9 million fewer SOV commuter VMT in the Phoenix region. The increase in HOV commuter VMT would yield a net commuter VMT reduction of 1.14 million per weekday. Given 250 workdays in the year, we would estimate an annual VMT reduction of about 285 million. Given a pollution emission factor of 18.15 per 1,000,000 auto VMT, we get a reduction of around 5181 tons per year. If 11% of the 728,000 SOV commuters are accepting the parking "buy-out" of $60 per month, we get an annual cost of about $58 million for this program. This cost divided by the 5181 tons of pollution reduction yields a cost of $11,195 per ton.

In the Tucson region, we start with a weekday SOV commuter VMT of 2.8 million. Reducing this by 11% yields a VMT reduction of 308,000 per weekday. Factoring in the increase in HOV VMT, we get a net commuter VMT reduction of 185,000 per weekday. Given 250 workdays in the year, we would estimate an annual VMT reduction of about 46 million. Given a pollution emission factor of 18.15 per 1,000,000 auto VMT, we get a reduction of around 839 tons per year. If 11% of the 135,000 SOV commuters are accepting the parking "buy-out" of $60 per month, we get an annual cost of about $10.7 million for this program. This cost divided by the 839 tons of pollution reduction yields a cost of $12,753 per ton.

***Transportation Allowances***

Transportation allowances (TA), like the parking cash-out program, can be highly effective given the right conditions exist. The ideal assumption for an effective TA program would be:

Employer-based TDM program is in effect.
SOV modal share is 75 %.
No transportation subsidy is currently provided.
Employee parking is provided free by the employer.
Sufficient alternatives to SOV travel exist.

The issues raised above concerning the cash-out measure are similiarly relevant to transportation allowances. In a sense, the subsidy is not much more than a payment to encourage employees to take a mode of travel other than the SOV. Therefore, some of the same people attracted to the cash-out program will also be interested in the transportation allowance. The payments for the TA are typically lower than that of cash-out programs so participation levels will be lower. For estimation purposes, a $30 per month payment is expected to reduce SOV travel by 7 percent.

In the Phoenix region, commuter SOV VMT per weekday is around 17.3 million. A 7% reduction would amount to 1.2 million VMT per weekday. Factoring in the increase in HOV VMT, this amounts to a net commuter VMT reduction of 727,000 per weekday. Assuming 250 workdays per year, the annual travel reduction would be about 182 million commuter VMT. At an emission rate of 18.15 tons per 1,000,000 auto VMT, we get an annual reduction of 3297 tons. With 7% of the 728,000 SOV commuters accepting the $30 per month allowance, we get an annual cost of around $18 million. This cost divided by the 3297 tons of pollution reduction yields a per ton price of $5460.

In the Tucson region, SOV commuter VMT per weekday is around 2.8 million. A 72% reduction would amount to 196,000 VMT per weekday. Factoring in the increase in HOV VMT, we get a net weekday commuter VMT reduction of 118,000. Assuming 250 workdays per year, the annual travel reduction would be about 29 million commuter VMT. At an emission rate of 18.15 tons per 1,000,000 auto VMT, we get an annual reduction of 534 tons. With 7% of the 135,000 SOV commuters accepting the $30 per month allowance, we get an annual cost of around $3.4 million. This cost divided by the 534 tons of pollution reduction yields a per ton price of $6367.

### *Parking Cash-Out/Transportation Subsidy Combination*

The combination of the two programs, while mutually reinforcing, will probably have an effect that is less than the sum of the two programs had they each been enacted alone. A total payment of $90 month may have a participation rate that results in a 14 percent decline in SOV travel.

In the Phoenix region, SOV commtuer VMT is around 17.3 million per weekday. A 14% reduction would amount to 2.4 million commuter VMT. Factoring in the HOV VMT increase, we get a net commuter VMT reduction of 1.45 million per weekday. Assuming 250 workdays per year, the annual travel reduction would be about 363 million commuter VMT. At an emmission rate of 18.15 tons per 1,000,000 auto VMT, we get an annual reduction of 6594 tons. With 14% of the 728,000 SOV commuters accepting the $90 monthly payment, we get an annual cost of around $110 million. This cost divided by the 6594 tons of pollution reduction yields a per ton price of $16,682.

In the Tucson region, SOV commtuer VMT is around 2.8 million per weekday. A 14% reduction would amount to 392,000 commuter VMT. Factoring in the HOV VMT increase, we get a net commuter VMT reduction of 235,000 per weekday. Assuming 250 workdays per year, the annual travel reduction would be about 59 million commuter VMT. At an emmission rate of 18.15 tons per 1,000,000 auto VMT, we get an annual reduction of 1067 tons. With 14% of the 135,000 SOV commuters accepting the $90 monthly payment, we get an annual cost of around $20 million. This cost divided by the 1067 tons of pollution reduction yields a per ton price of $18,744.

### *Vanpooling*

In the Phoenix region, the RPTA runs a third-party vanpool program that currently operates with 103 vans. Estimated annual operating costs are $400,000. The program serves approximately 1337 passengers per weekday. Each van has a weekday round trip of 60.4 miles. Consequently, the vans accumulate 6221 vehicle miles per weekday. Assuming 250 workdays per year, the annual vehicle mileage is about 1.6 million. If we assume that each passenger would have driven an SOV on a 60 mile round trip each weekday, we get an 80,220 VMT reduction. On an annual basis, this would amount to around 20 million miles. Subtracting the 1.6 million van miles from the reduced 20 million SOV miles yields a net reduction of 18.4 million commuter VMT per year. At an emissions rate of 18.15 per 1,000,000 auto VMT, we get 364 tons of pollution reduction. Dividing this tonnage into the $400,000 program cost yields a price of $1099 per ton.

### Telecommuting

Census data suggests that there are 587,649 and 97,729 commuters eligible to telecommute in Phoenix and Tucson, respectively. These numbers come from 1990 census data on occupations. We assume first that 25% of those eligible telecommute one day a week. This results in a 2.16% reduction in the morning trips of the eligible commuters and a 1.08% reduction in their afternoon trips, per week.[25] This amounts to an average reduction in commuter VMT of 1.62%.

In the Phoenix region, a 1.62% reduction of the 23 million commuter weekday VMT would be approximately 372,600. Assuming a 250 workday year, the annual commuter VMT reduction would be about 93 million. At an emission rate of 18.15 tons per 1,000,000 auto VMT, this amounts to 1691 tons per year.

In the Tucson region, a 1.62% reduction of the 3.7 million commuter weekday VMT would be approximately 59,940. Assuming a 250 workday year, the annual commuter VMT reduction would be about 15 million. At an emission rate of 18.15 tons per 1,000,000 auto VMT, this amounts to 272 tons per year.

The cost estimate assumes a $4 million government subsidy for the purchase of hardware for telecommuting. Taking the pollution reduction totals from Phoenix (1691) and Tucson (272) combined (1963), this works out to a cost of $2038 per ton.

Assuming that 25% of those eligible to telecommute due so on a half time basis results in a 5.39% reduction in morning trips and a 2.7% reduction in afternoon trips. [25]. This amounts to an average reduction in commuter VMT of 4.05%.

In the Phoenix region, a 4.05% reduction of the 23 million commuter weekday VMT would be approximately 931,500. Assuming a 250 workday year, the annual commuter VMT reduction would be about 233 million. At an emission rate of 18.15 tons per 1,000,000 auto VMT, this amounts to 4227 tons per year.

In the Tucson region, a 4.05% reduction of the 3.7 million commuter weekday VMT would be approximately 149,850. Assuming a 250 workday year, the annual commuter VMT reduction would be about 37 million. At an emission rate of 18.15 tons per 1,000,000 auto VMT, this amounts to 680 tons per year.

The cost estimate assumes a $4 million government subsidy for the purchase of hardware for telecommuting. Taking the pollution reduction totals from Phoenix (4227) and Tucson (680) combined (4907), this works out to a cost of $815 per ton.

**Flex-time**

For the flex-time option, it was assumed that SOV commuting was reduced by the mid-point of the 3% to 10% range indicated in the literature. This would give us a 6.5% decrease in SOV VMT. Multiplying this percentage by the 17.3 million SOV VMT per weekday yields an estimated VMT reduction of 1.1 million. Factoring in the increase in HOV VMT, we get a net commuter VMT reduction of 675,000 per weekday. Assuming 250 workdays in a year, we get 169 million fewer commuter VMT. Using the 18.15 tons per 1,000,000 auto VMT emissions factor, we estimate an annual tons of pollution reduction of 3061.

For Tucson, the 6.5% SOV commuter VMT reduction times the 2.8 million SOV commuter VMT for the region implies a VMT reduction of 182,000 per weekday. Factoring in the increase in HOV VMT, we get a net commuter VMT reduction of 109,000 per weekday. Assuming 250 workdays in a year, we get 27 million fewer commuter VMT. Using the 18.15 tons per 1,000,000 auto VMT emissions factor, we estimate an annual tons of pollution reduction of 495.

**Compressed Workweek**

Theoretically, the compressed workweek option could reduce commuter travel by 20% if every worker switched to a four ten-hour day workweek. However, it is not likely that it would be feasible for everyone to participate. An optimistic assumption would be that 25% of commuters participate. If 25% of commuters reduce their travel by one day in five (20%), we have a net reduction in commuter VMT of 5%. This percentage times the 23 million commuter VMT per weekday in Phoenix implies a reduction of 1.15 million. Assuming 250 workdays per year, we get an annual VMT reduction of 287 million. At the 18.15 tons per 1,000,000 auto VMT emission rate, we estimate an annual tons of pollution reduction of 5218.

This percentage times the 3.7 million commuter VMT per weekday in Tucson implies a reduction of 185,000. Assuming 250 workdays per year, we get an annual VMT reduction of 46 million. At the 18.15 tons per 1,000,000 auto VMT emission rate, we estimate an annual tons of pollution reduction of 839.

**Proximate Commuting**

For purposes of estimation, it is assumed that 40 percent of the 967,186 commuters in the Phoenix region work for multi-site employers and 60 percent of these multi-site employees do not work at the site nearest their home. The anticipated effect of implementing the program is that 10 percent of eligible employees will transfer to a work location nearer their home and that participating employees will reduce their VMT by 65 percent. This leaves a potential 23,200 commuters that might participate in this program in the Phoenix region. So, we have 23,200 commuters reducing their 11.9 mile average one-way trips by 65%. This gives us a weekday commuter VMT reduction of 359,000. Assuming 250 workdays, we get an annual commuter VMT reduction of 90 million. At an emmissions rate of 18.15 tons per 1,000,000 auto VMT, we have an annual pollution reduction of about 1629 tons.

In the Tucson region, we start with 176,965 commuters. Multiplying this number by the 40%, 60%, and 10% factors cited above, we get a possible participation by 4247 commuters. So, we have 4247 commuters reducing their 10.4 mile average one-way trips by 65%. This gives us a weekday commuter VMT reduction of 57,000. Assuming 250 workdays, we get an annual commuter VMT reduction of 14.4 million. At an emmissions rate of 18.15 tons per 1,000,000 auto VMT, we have an annual pollution reduction of about 261 tons.

Since employees would benefit by saving travel time and expense without having to give up their cars, no cost was estimated for this program.

## Regional TDM Program Measures

### Congestion Pricing

Congestion pricing estimates assume an area wide toll is imposed during the morning and evening peak periods. Studies conducted in the 1970s indicated that a $3 per day peak period toll would reduce peak period trips by 30%. Inflation adjusted the toll is $6 to $7. This is comparable to the 25 cent-per-mile toll currently in effect on California’s Route 91. MAGTPO estimates that about 39% of the VMT occurs during the three hour A.M. and three hour P.M. peaks combined.[90] A congestion pricing program may remove 30% of these trips.

For the Phoenix region, 39% of the weekday VMT amounts to 23 million. A 30% reduction would be 6.9 million VMT. Assuming that congestion is mostly a weekday problem, a 250 workday year implies an annual VMT reduction of 1725 million. Some of this travel, though, may merely be shifted to another time of day. Assuming that 50% of the trips are merely shifted to a different time of day would reduce the total VMT reduction to 863 million per year. Since all traffic would be affected, we use the average of all vehicles pollution emission factor of 19.04 tons per 1,000,000 VMT. This yields a reduction of 16,422 tons per year.

The remaining 16.1 million weekday peak period VMT (23 million minus the 6.9 million decrease in VMT) would pay a toll of 25 cents per VMT. This yields a toll revenue of $4 million per weekday and $1 billion per year. Dividing this annual toll revenue figure by the 16,422 tons of pollution reduction gives us a cost of $60,894 per ton.

For the Tucson region, 39% of the weekday VMT amounts to 5.8 million. A 30% reduction would be 1.8 million VMT. Assuming that congestion is mostly a weekday problem, a 250 workday year implies an annual VMT reduction of 435 million. Some of this travel, though, may merely be shifted to another time of day. Assuming that 50% of the trips are merely shifted to a different time of day would reduce the total VMT reduction to 218 million per year. Since all traffic would be affected, we use the average of all vehicles pollution emission factor of 19.04 tons per 1,000,000 VMT. This yields a reduction of 4141 tons per year.

The remaining 4 million weekday peak period traffic (5.8 million minus the 1.8 million decrease in VMT) would pay a toll of 25 cents per VMT. This yields a toll revenue of $1 million per weekday and $250 million per year. Dividing this annual toll revenue figure by the 4141 tons of pollution reduction gives us a cost of $60,372 per ton.

It should be emphasized that these costs would be borne directly by the road users. In contrast to the other congestion mitigation measures, congestion pricing would, from a public sector perspective, be "self-financing." That is, user tolls would more than cover the cost to implement and operate the system.

**HOV Facilities**

Phoenix has planned for 40 miles of HOV facilities. Estimated cost per lane mile is $4 million. Since each HOV mile is presumed to encompass two lane miles, the total cost of this option would be $320 million. Costs have been amortized over 10 years for purposes of cost-effectiveness comparison with other measures.

The Institute of Transportation Engineers estimates that HOV facilities will reduce peak period VMTs traveled on freeways by 5 percent. The national average for percentage of freeway VMTs to total VMTs is 30 percent. Estimates for Phoenix are that this percentage is closer to 20 percent, which implies a smaller reduction in VMTs. However, to estimate HOV emission impacts the 30% estimate is used to reflect additional capacity currently planned for or under construction.

If peak period VMT in the Phoenix region is 23 million per weekday, a 5% reduction would amount to 1.15 million. Assuming an effective 250 workday year, this would imply an annual VMT reduction of 287.5 million. Since the vehicles eligible for the HOV lane are passenger vehicles, we use the 18.15 tons per 1,000,000 auto VMT to get an annual pollution reduction of 5218 tons. This figure divided into the $32 million per year amortized cost of the HOV lanes yields a per ton cost of $6133.

**Park and Ride Lots**

According to the Regional Public Transportation Authority there are 61 park-and ride lots in the Phoenix metropolitan area, including three transit centers. These facilities provide for a total of 2546 parking spaces. Capacity utilization is approximately 23 percent, or 580 vehicles per day. If each of these vehicles had made an average round trip commute of 23.8 miles, the weekday commuter VMT reduction is 13,804. Assuming a 250 workday year, the annual VMT reduction is about 3.5 million. At 18.15 tons of pollutants per 1,000,000 commter VMT, this adds up to around 63 tons per year.

Fifty-six lots are negotiated for use by the RPTA with the property owners. There is no operational expense for the agency associated with these facilities. The expenses are $181,000 per year to maintain and secure three transit centers and two park-and-ride lots. Dividing these expenses by the 63 tons nets a cost of $2873 per ton.

## Public Transit

### Bus Service

Emissions impacts for bus service were calculated using estimates available in the Federal Transit Administration's *Transit Profiles* (1994). *Transit Profiles* provides annual passenger miles of 126,931,227, unlinked passenger "trips" of 32,150,467, revenue bus miles of 10,910,259, passenger fares of $16,047,079 (passenger fares cover approximately 31% of the annual opperating cost and 24% of the full annual cost of the bus system, taxes cover the remaining 76%), and operating costs of $51,608,425 and estimated annual capital costs of $15 million for the Phoenix regional public transit system. This $66.5 million cost divided by the 126, 931,227 passenger miles yields a cost of 52 cents per passenger mile. If we assume every one of these passenger miles would otherwise have been traveled in an SOV, we have an annual VMT reduction of 126,931,227 miles. Since these are passenger trips, we use the 18.15 tons per 1,000,000 auto VMT emission rate to produce a pollution reduction of 2304 tons. We must offset this with the pollutants emitted by the buses. In this case, we take the 10.9 million revenue bus miles multiplied by the diesel pollutant emission rate of 20.84 tons per 1,000,000 VMT to get a total of 227 tons per year. The net pollution reduction is then 2077 tons (2304 minus 227).

On the cost side, we have the $51.6 million operating cost plus an estimated $15 million capital cost for a total of $66.5 million per year. Dividing this by the 2077 tons of pollution reduction, we get a cost of $32,017 per ton.

RPTA also looked at two levels of expanded bus and dial-a-ride service. [91] In the moderate expansion option, revenue miles of service is expanded to 20 million miles per year. Operating costs rise by $45 million (counting the portion covered by passenger fares, approximately $13.5 million). Capital costs rise by $27 million (counting both the federal and local share) per year. This puts the total cost for this expansion of service at $72 million per year. Passenger fares are expected to cover about 19% of the full cost of this bus service expansion. RPTA expects to increase unlinked trips by 10.5 million per year and to boost unlinked trip lengths from the current level of 3.9 miles per trip to 6 miles per trip to produce a passenger miles of travel increase of 63 million per year. Dividing the additional expense of $72 million per year by the projected 63 million additional passenger miles of travel yields a cost of $1.14 per passenger mile of service. If we assume that all of this travel would have otherwise gone via SOV, we would multiply the 63 million by the 18.15 tons per 1,000,000 auto VMT emission rate to get a pollution reduction of 1143 tons per year. There is no net reduction for the additional bus miles because it is assumed that all new vehicles are zero-emission vehicles. Dividing this tonnage into the $72 million of additional transit cost yields a price of $62,992 per ton.

In the high expansion option, revenue miles of service is expanded to 20 million miles per year. Operating costs rise by $90 million (counting the portion covered by passenger fares, approximately $27 million). Capital costs rise by $54 million (counting both the federal and local share) per year. This puts the total cost for this expansion of service at $144 million per year. Passenger fares are expected to cover about 19% of the full cost of this bus service expansion. RPTA expects to increase unlinked trips by 28 million per year and to boost unlinked trip lengths from the current level of 3.9 miles per trip to 6 miles per trip to produce a passenger miles of travel increase of 168 million per year. Dividing the $144 million in annualized costs by the projected additional 168 million passenger miles of travel yields a cost of 86 cents per passenger mile of service. If we assume that all of this travel would have otherwise gone via SOV, we would multiply the 168 million by the 18.15 tons per 1,000,000 auto VMT emission rate to get a pollution reduction of 3049 tons per year. There is no net reduction for the additional bus miles because it is assumed that all new vehicles are zero-emission vehicles. Dividing this tonnage into the $144 million of additional transit cost yields a price of $47,229 per ton.

Tucson's Sun Tran has the following 1994 statistics. Passenger miles were 59,418,482. Passenger trips were 17,299,305. Unlinked trip length was 3.4 miles per trip. Passenger fares were $5,114,846. Operating costs were $24,985,848. Capital costs are estimated at $9 million per year. Passenger fares cover about 20% of operating costs and 15% of full costs. Cost per passenger mile of service are about 59 cents ($34 million in costs divided by 59.4 million passenger miles. Revenue bus miles were 6,582,016. If we assume every one of these passenger miles would otherwise have been traveled in an SOV, we have an annual VMT reduction of 59.4 million miles. Since these are passenger trips, we use the 18.15 tons per 1,000,000 auto VMT emission rate to produce a pollution reduction of 1078 tons. We must offset this with the pollutants emitted by the buses. In this case, we take the 6.6 million revenue bus miles multiplied by the diesel pollutant emission rate of 20.84 tons per 1,000,000 VMT to get a total of 137 tons per year. The net pollution reduction is then 941 tons (1078 minus 137).

On the cost side, we have the $25 million operating cost plus an estimated $9 million capital cost for a total of $34 million per year. Dividing this by the 941 tons of pollution reduction, we get a cost of $36,132 per ton.

**Natural Gas Bus Service**

Emissions impacts for a fleet of natural gas buses were calculated under the assumption that natural gas buses have zero emissions. (This is a generous assumption, but given the large difference between passenger and revenue miles it has little effect on the result.) Thus, the estimate of the net impact of a natural gas bus fleet is that the 2304 tons of pollution reduction from reduced auto travel is not offset by any bus pollution.

The cost estimate for natural gas buses is the same for that of normal bus service plus the cost of replacing the bus fleet. It is assumed that each bus equipped with a natural gas engine cost $90,000. If 300 buses are replaced, this cost would amount to $27 million. The cost is amortized over ten years. This brings the additional annual charge to $2.7 million. This plus the $72 million total annual cost for the existing bus service comes to $74.7 million. Dividing this by the 2304 tons of pollution reduction yields a price of $32,422 per ton.

**Rail Transit**

We make two estimates for rail transit. The first estimate for rail transit is based on the 1988 ValTrans proposal. [79] Looking longer term, the RPTA estimated that there would be 189 million boardings per year in 2020. Assuming that each boarding is associated with a 3.9 mile trip (the current average for the bus system, other cities with rail transit systems have average unlinked passenger trip lengths of similar magnitude) implies a reduction of 737 million VMTs a year by 2020. Assuming that all of these passengers would have otherwise driven SOVs, we multiply this 737 million VMT by the estimates of passenger car emissions of 11.5 tons per 1,000,000 auto VMT a pollution reduction of 8475 tons for the year 2020. (This assumption of 100% SOV conversion is excessively optimistic. Typically, the majority of rail passengers were formerly bus riders. In Los Angeles, only 10% to 15% of the passengers on the new rail transit "Blue Line" were formerly SOV drivers, 85% to 90% were formerly bus riders. [95]) The estimated total quantity of pollution reduction between now and 2020 under a ValTrans type of rail option would be about 90,000 tons. The total cost of the ValTrans option in today's dollars is estimated at $12.7 billion. Therefore the average cost per ton of pollution reduction would be about $140,000 per ton. The average cost per passenger mile of service over the period between 1996 aqnd 2020 is about $1.44. In the near term, the impacts would be much smaller and the costs much higher due to the heavy "front-end" start-up expense and the time it would take to build the system and attract riders. If we amortize the $12.7 billion cost over the 24 year 1996-2020 period, we get an annual expense of $530 million. By the fifth year (the end of our "near term" framework for evaluating the various congestion mitigation measures), it would be optimistic to think that the system would have completed 20% of its track mileage. This would amount to around 21 miles of track. If ridership could match that achieved by the 21 mile Miami rapid rail transit system after ten years of operation, there would be about 50,000 passenger trips per weekday. Assuming that weekend traffic is about half that of weekdays, there would be about 15 million trips per year. Using a 4 mile typical transit trip length (Miami averages about 4 miles per passenger trip, Phoenix transit currently averages about 4 miles per passenger trip), the annual passenger miles of travel would approximate 60 million. At 18.15 tons of pollution per 1,000,000 auto VMT, the pollution reduction potential would be approximately 1089 tons. Dividing this into the $530 million annual cost yields a price of around $486,685 per ton.

More recently, RPTA has come forward with a more modest rail transit proposal. [91] In this proposal, there are only 20 miles of at-grade (i.e., running on the same level with the streets) rather than 103 miles of elevated tracks. This substantially reduces the cost of construction. Impacts on SOV travel are also smaller. (There would also be some degree of impedence of motor vehicle traffic that had to be stopped to allow passage of the at-grade trains. The quantity of this impedence is not known and is consequently ignored in the estimates of the pollution reduction potential of this option.) Operating costs are estimated at $14.8 million per year (counting the portion covered by passenger fares, approximately $4.4 million). Capital costs are estimated at $41.8 million (counting both the federal and local share) per year. This puts the total cost for this rail service at $56.6 million per year. This probably understates the likely cost. Nine out of ten new rail transit systems exceed original cost estimates. On average, actual costs are 50% higher than originally estimated costs.[93] If RPTA's cost and ridership forecasts are fulfilled, passenger fares would cover about 8% of the full cost of this rail option. Given the $56.6 million per year cost and the 55.2 million passenger miles of travel, the cost per passenger mile for this service would be approximately $1.03. RPTA expects this train to account for 9.2 million unlinked trips per year and to boost unlinked trip lengths from the current level of 3.9 miles per trip to 6 miles per trip to produce a rail transit passenger miles of travel of 55.2 million per year. This probably overstates the likely ridership. Nine out of nine new rail transit systems that made ridership forecasts fell short by an average of 65%.[93] In addition, the assumption that 100% of train riders would otherwise have driven single-occupant autos is excessively optimistic. Typically, the majority of rail passengers were formerly bus riders. In Los Angeles, only 10% to 15% of the passengers on the new rail transit "Blue Line" were formerly SOV drivers, 85% to 90% were formerly bus riders. [95] If we deduct the 85% passengers that would be diverted to rail from buses in the Phoenix region, we get an estimate of newly generated rail passenger miles of 8.3 million per year. To estimate the air pollution impact, we would multiply the 8.3 million new passenger miles per year by the 18.15 tons per 1,000,000 auto VMT emission rate to get a pollution reduction of 150 tons per year. Dividing this tonnage into the $56.6 million of additional transit cost yields a price of around $377,000 per ton.

## Intelligent Transportation Systems

### Traffic Signal Synchronization

The ADEQ Mobile 5 model employs an estimated average trip speed of 27.8 miles per hour. This model is capable of translating changes in trip speed to changes in emissions. The optimal speed to minimize emissions has been estimated to be about 48 miles per hour.[89] By increasing the average speed it is possible to decrease emissions without reducing VMTs.

In Texas, the comprehensive traffic light synchronization program for 1348 intersections resulted in an estimated reduction of 15,429 gallons of fuel burned per intersection, per year. If Phoenix could achieve similar results for 1500 intersections, we would expect a fuel consumption reduction of around 23 million gallons per year. Using the current average of 19.2 miles per gallon for all vehicles, we would save the equivalent of 444 million VMT per year. Given our 19.04 tons of emissions per 1,000,000 VMT for all vehicles, this implies an equivalent pollution reduction of 8461 tons per year.

The cost for a system of this type in Texas was approximately $5700 per intersection. There were 1500 intersections included in this estimate for a total cost of $8.55 million. Since the technology in this area is rapidly evolving, we did not amortize these costs. Thus, we assume full replacement/updating of all 1500 intersections every year. This probably overstates the cost of this congestion mitigation measure. Dividing the 8461 tons into the $8.55 million cost yields a price of $1011 per ton of pollution reduction.

California's Fuel Efficient Traffic Signal Management (FETSIM) Program completed in 1991 reported reduction of fuel consumption by 8.1 percent, while the number of stops and delays declined by 14 percent [81]. The program involved retiming of 9,000 signalized intersections. The program did not allow for the upgrade of older, outdated equipment. Therefore, the results reflect only the retiming of signals already within a coordinated system. Assuming the Phoenix region could experience this magnitude of results would imply an 8.1% decline in emisions. Taking the annual total emissions for the region of 372,388 tons, an 8.1% reduction would amount to 30,163 tons. If we accept the high end of the estimated cost for upgrading an intersection ($9,000), we get a total cost of $13.5 million for 1500 intersections. Since the technology in this area is rapidly evolving, we did not amortize these costs. Thus, we assume full replacement/updating of all 1500 intersections every year. This probably overstates the cost of this congestion mitigation measure. If we divide this $13.5 million cost by 30,163 tons of annual pollution reduction we obtain an estimated cost of $448 per ton.

In 1993 Maricopa County DOT estimated that a comprehensive signal synchronization program for 1564 intersections would reduce pollution by about 2.5% and cost $23.1 million to implement[94] (about $25 million in inflation adjusted 1996 dollars). Since annual Phoenix region pollution is estimated at 372,388 tons, a 2.5% reduction would amount to 9310 tons. If the cost to implement this program is $25 million, the cost per ton of pollution reduction would be approximately $2685.

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