Effects of Cordon Pricing on PM2.5 Production in an Inversion Prone Area: A Case Study in Cache County, Utah.

Brandon Charles Brady
Utah State University

Follow this and additional works at: https://digitalcommons.usu.edu/gradreports

Part of the Civil and Environmental Engineering Commons

Recommended Citation
https://digitalcommons.usu.edu/gradreports/322

This Thesis is brought to you for free and open access by the Graduate Studies at DigitalCommons@USU. It has been accepted for inclusion in All Graduate Plan B and other Reports by an authorized administrator of DigitalCommons@USU. For more information, please contact digitalcommons@usu.edu.
EFFECTS OF CORDON PRICING ON PM$_{2.5}$ PRODUCTION
IN AN INVERSION PRONE AREA:
A CASE STUDY IN CACHE COUNTY, UTAH
by
Brandon Charles Brady

A project submitted in partial fulfillment
of the requirements for the degree

of

MASTER OF SCIENCE

in

Civil and Environmental Engineering

Approved:

Kevin Heaslip
Major Professor

Anthony Chen
Committee Member

Randal Martin
Committee Member

UTAH STATE UNIVERSITY
Logan, Utah
2011
ABSTRACT

Effects of Cordon Pricing on PM$_{2.5}$ Production in an Inversion Prone Area: A Case Study in Cache County, Utah

by

Brandon Charles Brady, Master of Science
Utah State University, 2011

Major Professor: Dr. Kevin Heaslip
Department: Civil and Environmental Engineering

The main objective of this research was to investigate the possibility of a cordon area pricing scheme in an inversion prone area to reduce fine particulate matter (PM$_{2.5}$) production and to give decision makers more options when it comes to reducing pollution. This project presents a case study in Cache County, Utah to determine the impact that a cordon area-pricing scheme would have in reducing the pollution. Cache Metropolitan Planning Organization (CMPO) provided a CUBE Voyager model of the county that was used and changed to measure vehicle miles travelled (VMT) from different scenarios for the years 2010, 2020, 2030, and 2035. A literature review was done on other cordon area pricing schemes from around the world to compare and use similar number in the modeling. Then the VMT was used to measure emissions using the emission rates from the CMPO’s MOBILE6.2 emissions model for all years.

This project explains how the CUBE Voyager model of Cache County was developed and which parts were changed to model a cordon area-pricing scheme. The
script file in the highway assignment section of the model was changed and only the external trips were reduced. The model has two different classifications of vehicles, long and short, that were changed differently for each scenario. There were four scenarios run in the model with two different types of data sets. Scenario 1 was a “do nothing” scenario that was run without any changes in the model and used as a base for comparison for the other scenarios. Scenario 2 was to reduce the external trips for both long and short vehicle trips by 20%. Scenario 3 was to reduce long vehicle external trips by 50% and short vehicle external trips by 20%. Scenario 4 was to reduce the long vehicle external trips by 100% and the short vehicle external trips by 20%. The two different types of data sets was one with the 2010 network used for all years denoted as a “No Build” network and the other used the data with each phase of highway capacity projects completed denoted as “With Phases.” The pollution reduction for all the scenarios was analyzed and recommendations were given.

(85 pages)
DEDICATION

This project is dedicated to my family and friends. To my family and friends for their support and patience through this educational process. I couldn’t have done it without you.
ACKNOWLEDGMENTS

I would like thank Dr. Kevin Heaslip for his guidance and patience throughout the research and writing process. I would also like to thank Jeff Gilbert for providing the model of Cache County and Dr. Randy Martin for all the support on the environmental side of the project. I would also like to thank Dr. Chen for his help and advice with the modeling process.

Brandon Brady
# CONTENTS

<table>
<thead>
<tr>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABSTRACT</td>
</tr>
<tr>
<td>DEDICATION</td>
</tr>
<tr>
<td>ACKNOWLEDGMENTS</td>
</tr>
<tr>
<td>LIST OF TABLES</td>
</tr>
<tr>
<td>LIST OF FIGURES</td>
</tr>
</tbody>
</table>

## CHAPTER

1. **INTRODUCTION**
   1.1 Research Problem | 1
   1.2 Necessity for Research | 2
   1.3 Past Research Approaches | 4
   1.4 Research Approach | 7
   1.5 Anticipated Contributions | 8
   1.6 Project Organization | 8

2. **LITERATURE REVIEW**
   2.1 Introduction | 10
   2.2 Pollution Problem | 10
   2.2.1 PM$_{2.5}$ Formation | 12
   2.2.2 PM$_{2.5}$ Production vs. Levels | 13
   2.2.3 PM$_{2.5}$ in Cache County | 13
   2.2.4 History of PM$_{2.5}$ | 14
   2.2.5 Special Challenges in Cache County | 17
   2.2.6 Costs of PM 2.5 in Cache County | 18
   2.3 Toll Roads | 19
   2.3.1 Background | 20
   2.3.2 Roadway Pricing Successes | 23
   2.3.3 Cordon Pricing | 24

3. **METHODOLOGY AND ASSUMPTIONS**
<table>
<thead>
<tr>
<th>Table</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Historical PM 2.5 Levels in Cache Valley</td>
<td>14</td>
</tr>
<tr>
<td>2. People at Risk of Airborne Pollution in Cache County</td>
<td>19</td>
</tr>
<tr>
<td>3. Examples of Successful Toll Road</td>
<td>23</td>
</tr>
<tr>
<td>4. Exemptions and Discounts in Central London</td>
<td>26</td>
</tr>
<tr>
<td>5. Percent in Change of Vehicles Entering and Exiting Condon Area</td>
<td>27</td>
</tr>
<tr>
<td>6. Toll Classes Based on Euro Emission Standards</td>
<td>30</td>
</tr>
<tr>
<td>7. European Emissions Standard Classification</td>
<td>31</td>
</tr>
<tr>
<td>8. Ecopass Toll Rates (in Euros)</td>
<td>32</td>
</tr>
<tr>
<td>9. Vehicle Class Change after Toll Implementation (vehicles/day)</td>
<td>33</td>
</tr>
<tr>
<td>10. Summary of Cordon Pricing Areas</td>
<td>34</td>
</tr>
<tr>
<td>11. Description of Large and Medium Districts</td>
<td>42</td>
</tr>
<tr>
<td>12. GOPB Employment Data Classification</td>
<td>44</td>
</tr>
<tr>
<td>13. Emissions Rates</td>
<td>55</td>
</tr>
<tr>
<td>14. Do Nothing Scenario Results</td>
<td>64</td>
</tr>
<tr>
<td>15. 20% Trip Reduction for Long &amp; Short Vehicles</td>
<td>67</td>
</tr>
<tr>
<td>16. 20% Short &amp; 50% Long Vehicle Trip Reduction</td>
<td>69</td>
</tr>
<tr>
<td>17. 20% Short &amp; 100% Long Vehicle Trip Reduction</td>
<td>71</td>
</tr>
<tr>
<td>18. Summary of Change in NO\textsubscript{x} for No Build Network</td>
<td>73</td>
</tr>
<tr>
<td>19. Summary of Change in NO\textsubscript{x} for With Phases Network</td>
<td>74</td>
</tr>
</tbody>
</table>
# LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Historical PM(_{2.5}) Levels in Cache Valley</td>
<td>15</td>
</tr>
<tr>
<td>2.</td>
<td>Average Monthly and Annual PM(_{2.5}) Levels</td>
<td>15</td>
</tr>
<tr>
<td>3.</td>
<td>Vehicle Miles Traveled and Roadway Lane Miles</td>
<td>22</td>
</tr>
<tr>
<td>4.</td>
<td>CMPO Model Directory Layout</td>
<td>38</td>
</tr>
<tr>
<td>5.</td>
<td>TAZ Structure in CMPO Model</td>
<td>39</td>
</tr>
<tr>
<td>6.</td>
<td>Example of TAZ in a Network</td>
<td>40</td>
</tr>
<tr>
<td>7.</td>
<td>Map of Large and Medium Districts</td>
<td>41</td>
</tr>
<tr>
<td>8.</td>
<td>GOPB Residential Control Totals</td>
<td>43</td>
</tr>
<tr>
<td>9.</td>
<td>GOPB Employment Controls</td>
<td>45</td>
</tr>
<tr>
<td>10.</td>
<td>Base Network 2008</td>
<td>47</td>
</tr>
<tr>
<td>11.</td>
<td>USU Student Distribution from Fall 2008</td>
<td>48</td>
</tr>
<tr>
<td>12.</td>
<td>Screen Shot of Traffic Assignment in Model</td>
<td>52</td>
</tr>
<tr>
<td>13.</td>
<td>Matrix Format</td>
<td>53</td>
</tr>
<tr>
<td>14.</td>
<td>Cache County Proposed Toll Area</td>
<td>62</td>
</tr>
<tr>
<td>15.</td>
<td>Area in CMPO Model where the Script was changed</td>
<td>66</td>
</tr>
<tr>
<td>16.</td>
<td>Different VMT Levels for Scenarios 1 and 2</td>
<td>67</td>
</tr>
<tr>
<td>17.</td>
<td>Different VMT Levels for Scenarios 1 and 3</td>
<td>70</td>
</tr>
<tr>
<td>18.</td>
<td>Different VMT Levels for Scenarios 1 and 4</td>
<td>72</td>
</tr>
<tr>
<td>19.</td>
<td>Levels for all Scenario with No Build Network</td>
<td>74</td>
</tr>
<tr>
<td>20.</td>
<td>NO(_x) Levels for all Scenario using With Phases Network</td>
<td>75</td>
</tr>
<tr>
<td>21.</td>
<td>VMT Change for All Scenarios for No Build Network</td>
<td>76</td>
</tr>
</tbody>
</table>
22. VMT Change for All Scenarios for With Phases Network………………………76
CHAPTER 1
INTRODUCTION

1.1 Research Problem

Inversions occur when the atmosphere layer closest to the Earth is cooler than the air above it, which can lead to excessive pollution build up. The pollution gets trapped in a geographic area, like a valley, and can have adverse effects on the health of those living within that area. In some areas it has become a “tragedy of the commons”, a concept made famous by Garrett Hardin (Hardin, 1968). Hardin illustrates this concept with herders using a common piece of land to graze their cattle. Each farmer faces the private incentive to produce more at the expense of others and then the common resource is overused and depleted. Just like with the pollution in a valley, each driver benefits from using the infrastructure, but the air all drivers’ breath becomes unhealthy.

This project deals with pollution in a local area enhanced by limiting factors such as meteorology and topography. One of the main contributors to the pollution in geographical areas where inversions are prevalent is the motorized vehicle. Places like Logan, Utah, Salt Lake City, Utah, Los Angeles, California, Phoenix, Arizona, and Mexico City, Mexico all have a problem with pollution that can be related to motorized vehicle use. The pollutants produced by motorized vehicle use affect the health of the surrounding communities. Different methods can be used to reduce the pollution produced by motorized vehicles, through emissions testing, or controlling how much the motorized vehicle is used with a user’s tax.
This project used a case study of Cache County, Utah where the pollutant particle matter 2.5 (PM$_{2.5}$) is the main concern during the winter months. The Environment Protection Agency (EPA) explains that PM$_{2.5}$ is a particulate matter with a diameter less than or equal to 2.5 micrometers. Cache County is located in a valley that is at an elevation of around 4,500 feet and is surrounded by mountains up to 10,000 feet of elevation that trap the PM$_{2.5}$ in through inversions of colder temperatures on the valley floor than the mountain tops. The research done in this project can be used for policy makers when it comes to alternatives to reduce pollution in Cache Valley.

This introduction explores the background conditions justifying the research. First, past research is summarized to determine existing approaches used for accounting and measuring the current problem. Next is explained why new possibilities, like a tax, may be able to reduce the problem. Specifically, cordon area pricing is detailed and compared to alternatives in order to think dynamically about what means would address the pollution concerns for the valley.

1.2 Necessity for Research

Cache County, an agricultural community, in recent years has seen a substantial increase in population, as industry and the research university continues to attract residents. With the population growth in Cache County of 89,866 in 1998 to 112,616 in 2008, about a 20% increase in 10 years. An increase in population increases transportation demand. Solving the pollution problem is key for the continual growth. Cache County is a formerly rural region approximately 1,164 square miles in size, anchored by the city of Logan, which includes Utah State University (USU). It is rapidly urbanizing and becoming developed, and expects to see a roughly doubling in population
over the next 25 years. Though its emissions levels and roadway use is not particularly unusual, the Cache County’s combination of meteorological, agricultural and urban emissions, and topographical characteristics, mountain valley, regularly result in unhealthy levels of PM$_{2.5}$, which is generally experienced as smog.

During the months of November through February, Cache County, Utah, has some of the worst air quality in the country. The high mountains surrounding the region keep the pollutants from dispersing laterally, and the frequent winter inversions, where the air is colder at lower elevations than at higher ones, traps the pollutants close to the ground. Air quality levels frequently fail government standards, causing substantial health and quality of life costs such as lung and heart problems. According to the EPA, “roughly one out of every three people in the United States is at a higher risk of experiencing PM$_{2.5}$ related health effects. One group at high risk is active children because they often spend a lot of time playing outdoors and their bodies are still developing. In addition, oftentimes the elderly population is at risk. People of all ages who are active outdoors are at increased risk because, during physical activity, PM$_{2.5}$ penetrates deeper into the parts of the lungs that are more vulnerable to injury” (EPA, 2011a). When exposed to even small levels of particulate matter, people with existing heart or lung diseases such as asthma, chronic obstructive pulmonary disease, congestive heart disease, or ischemic heart disease are at increased risk of premature death.

The most serious pollution problem afflicting the region is the PM$_{2.5}$ levels, especially during wintertime. The PM$_{2.5}$ is not always emitted directly from vehicles tailpipes; rather the volatile organic compounds (VOC) and nitrogen oxides (NO$_x$) react with the ammonia in the air (sustained at very high levels by the valley’s agricultural
activity) to create NH₄NO₃, which comprises the vast majority of PM₂.₅ in the region (UDEQ, 2010a). The focus only on vehicular PM₂.₅, as opposed to total PM₂.₅ is not always appropriate, but it is applicable in Cache County. The region lacks much heavy industry or major power plants that would produce PM₂.₅. It does have a small diesel-power secondary power plant to supply electricity in times of high demand, but it only tends to be turned on in the summer, when PM₂.₅ levels are less of a concern, and overall it provided negligible contributions. USU had a coal-fired heating plant but it was replaced with a modern natural gas plant. Currently the majority of PM₂.₅ in Cache County can be attributed to vehicle emissions; it is a situation that merits rapid action (UDEQ, 2010a). Non-vehicular emissions are not predicted to vary much over time, so can be considered a constant background to vehicular PM₂.₅ production. Because of the apparent problem there have been past attempts at solutions.

1.3 Past Research Approaches

This is not a new problem for Cache County. The problem has been researched and solutions have been proposed, but none have been implemented. A vehicle miles travelled (VMT) tax has been researched at USU to find that annual particulate emissions would be reduced between 7% and 11% with a tax of $0.003 per mile on passenger cars and $0.01 per mile tax on light-duty trucks. If the tax burden were doubled for both passenger cars and trucks, the decrease in annual particulate emissions would be between 12% and 23% (Carroll-Larson and Caplan, 2009). This is a good idea but there are limitations to a VMT tax, which include, only taxing the VMT that occurs within the area and having people correctly reporting their VMT. All vehicles could be outfitted with a
GPS to track the miles but this would be a costly process and many would appose it because of privacy rights.

USU, Logan City, and the Bear River Health Department have take measures to reduce the pollution. USU uses natural gas buses for the on-campus shuttles and replaced coal-fired heating plant with a natural gas plant. Logan City has synchronized traffic lights along Main Street to reduce the amount of congestion. The Bear River Health Department established red-yellow-green wood-burning days and a smoking vehicle program that is enforced by police (UDEQ, 2010a). There are also electronic signs that are placed at the north and south ends of Logan Main Street during winter months to inform drivers when air pollution reaches unhealthy levels. All of these solutions have helped but not enough to keep the pollution levels within the EPA standards.

Another solution to the problem that has been researched is assessing a gas tax. Devarajan and Eskeland (1996) state that there is a weak connection between emissions and fuel efficiency. Meaning that because a vehicle gets bad gas mileage does not mean that the vehicle emits more pollution. A gas tax would make people change from their gas-guzzlers to a more gas efficient vehicle but not necessarily drive less. In Cache Valley it a seasonal problem so drivers would switch vehicles for the winter months then switch back after. Also, the problem is controlling the localized pollution so if a gas tax were only assessed in Cache Valley, where the problem is, then drivers would go outside the valley for fuel.

Emission testing is another idea that could help, but has not been assessed. Emission testing could help but there are certain vehicles that would be exempt, like farm vehicles, which make up a large part of the problem. Each state has their own slightly
different protocols, and some states do not require any testing at all, but the general procedure is to require all vehicles older than 1996 (with some exceptions) to have their tailpipe emissions checked by licensed service stations, which examine NO\textsubscript{x}, VOC, PM\textsubscript{10}, CO, and other pollutants and vehicles newer than 1996 have a computer test. If any of the levels are higher than the federally mandated level, the vehicle must be repaired sufficiently to allow it to pass the test within a given period of time. In Utah, the general parameters for emissions testing are that all vehicles registered in Davis, Salt Lake, Utah, or Weber counties, made in 1968 or later must be tested either annually or biannual depending on vehicle age (Utah DMV, 2010). There is also a maximum fix-it-price for the vehicles that do not meet the standards. There are no required emissions testing in other counties in the State of Utah.

In Cache Valley there is a public transit system called the Cache Valley Transit District (CVTD) that is fully subsidized through local sales tax and Federal Transit Administration Urbanized Area Formula Program grants and has no extra charge for riders. CVTD currently runs 15 routes all around Cache Valley and in October 2008 the ridership for the month was over 200,000. However, this was a record and was 13.76\% increase year to date from January to October (CVTD, 2010). A study done by Utah State University shows that the majorities of riders do not own a vehicle and ride the bus out of necessity. With a cordon area-pricing scheme it would shift the mode of transportation from personal vehicles to public transit.

All the past research and approaches have helped formulate the problem and the necessity to do something about the pollution in Cache County. Because nothing has been done about the apparent problem a different research approach is necessary to give
more options to the policy makers about the best way to approach and solve the pollution problem in the county.

1.4 Research Approach

This project proposes a cordon area-pricing scheme in Cache County to reduce PM$_{2.5}$ by reducing the number of vehicles entering, leaving, and passing through the county during winter months of November to February. Other approaches have problems with the pollution being local and seasonal when it comes to controlling the VMT just within the area. Traditional tolling will not work because if there are tollbooths in place it would cause more congestion and the idling of the vehicles would only contribute more to the pollution and be an inconvenience. The research proposes a differentiation based charge, based on emission standards in a cordon area to reduce pollution. The purpose of the research was not to figure what the differentiation charge will be, but rather the amount of external trips that have to be reduced to decrease the PM$_{2.5}$ levels. This was done by looking at other cordon areas around the world and what effects they have had on traffic and pollution.

A large cordon area pricing was done in Stockholm, Sweden and was approximately 30 km$^2$ and traffic volumes were reduced by 23.8% (Rotaris et al., 2010). A medium area where cordon area pricing was done in central London, England and was approximately 22 km$^2$ when it was first implemented and then increased to 40 km$^2$ then decreased back to its original 22 km$^2$. The number of vehicles that entered central London decreased by about 22% after the toll was implemented (Rotaris et al., 2010).

Smaller cordon area pricing schemes were conducted in Milan, Italy and Singapore with an area of 8 km$^2$ and 7 km$^2$, receptively. In Milan the cordon area-
pricing scheme was implemented to reduce pollution instead of congestion like the others in Stockholm, London, and Singapore. Milan had around a 20% decrease in vehicles entering the area, which lowered the PM$_{10}$ by 23% (Rotaris et al., 2010). Singapore reduced peak hour traffic per business day by 45% (Larson and Sasanuma, 2010).

The research done was modeled after the locations talked about above, mainly, Milan and London. Milan was picked because it is the only cordon area-pricing scheme to be implemented to reduce pollution, which was the objective of this research. London was picked because of the success and literature that is available on it.

1.5 Anticipated Contributions

This research provides an alternate means to reducing pollution in an area that is prone to inversions. It can also be used for the Cache Metropolitan Planning Organization (CMPO) to determine the best method when it comes to reducing the pollution in Cache County. The results will show the best method when it comes to using cordon area pricing in a smaller area.

1.6 Project Organization

The research conducted and presented in this project are as follows:

Chapter 2: Literature Review

Chapter 3: Methodology and Assumptions

Chapter 4: Modeling and Findings

Chapter 5: Conclusion and Recommendations

The literature review in Chapter 2 covers the different literature done on pollution in general then on the problem specifically in Cache Valley. Then it covers past toll road and area success and failure, and the importance of it in certain situations. Chapter 3
covers the methodology of the model and why certain parameters were chosen and assumptions made. Then in Chapter 4 the modeling done is shown and findings are stated. In the conclusion, Chapter 5, the findings from Chapter 4 are summarized and a suggestion is made about the best way to use a cordon area pricing scheme in Cache County.
CHAPTER 2
LITERATURE REVIEW

2.1 Introduction

In this chapter literature about pollution problems in general and also the specific problems facing Cache Valley are reviewed. Then a review about the importance of toll roads and the uses of them are discussed. Then some back ground information is given about toll roads and then a review was done about cordon pricing in London, Singapore, and Milan.

2.2 Pollution Problem

The Clean Air Act requires the EPA to establish the National Ambient Air Quality Standards (NAAQS) for seven pollutants that are harmful to public health and the environment. The seven pollutants are:

- Carbon Monoxide (CO)
- Lead (Pb)
- Nitrogen Dioxide (NO₂)
- Particulate matter with a diameter less than or equal to 10 micrometers (PM₁₀)
- Particulate matter with a diameter less than or equal to 2.5 micrometers (PM₂.₅)
- Ozone (O₃)
- Sulfur Dioxide (SO₂)

The EPA only had six pollutants until they determined that the PM₁₀ standard did not sufficiently protect the public health and the environment from the impacts of particles 2.5 micrometers and less (Grant, 1998). The most serious pollution problem
afflicting the Cache County is the PM$_{2.5}$ levels, especially during wintertime months. PM$_{2.5}$ or “Fine Particles” refers to particulate matter (airborne solids) less than 2.5 micrometers in diameter. By comparison, PM$_{10}$ are particles between 10 and 2.5 micrometers; these comprise the two main groups of particulate matter pollution. One large difference between the two is that being larger, PM$_{10}$ generally settles to the ground in a matter of hours, but PM$_{2.5}$ can remain airborne for weeks if there is no precipitation (rain or snow), and it is this distinction that makes PM$_{2.5}$ such a major issue in Cache County.

PM$_{10}$ reduction makes for cleaner air that is visually better but does not necessarily mean better health. According to the EPA, PM$_{10}$ particles are big enough that they can be stopped my nose hairs and mucus in the lungs. However, if PM$_{10}$ level get too high they can pose health problems, like they have in China (Hammitt and Zhou, 2005). Because PM$_{2.5}$ particles are so small they can bypass the natural protections of the body and imbed themselves deep in the lungs causing health problem. So PM$_{2.5}$ reduction means that there will be healthier air.

While it is a consideration in Cache County, PM$_{10}$ production is simply not high enough to present a major public health issue. However, the region is plagued by a particular set of topographical and meteorological conditions that allow for unsatisfactorily high PM$_{2.5}$ concentrations. The high mountains (up to 1391 meters above the valley floor) stop the PM$_{2.5}$ from spreading outward, and the frequent inversions (colder temperatures on the valley floor than on the higher mountain slopes), prevent the particles from spreading upwards (Silva et al., 2007). The PM$_{2.5}$ thus concentrates on the
valley floor to such an extent that during the winter Logan often has the worst air in the country according to the EPA standards (Malek, et al., 2006).

2.2.1 PM$_{2.5}$ Formation

PM$_{2.5}$ can come from either primary or secondary sources. Primary PM$_{2.5}$ are those particles that are emitted directly into the environment, such as through wood burning stoves, while secondary PM$_{2.5}$ are particles that are created through pollutants that are emitted as gases and then chemically change in the air to become a solid. Secondary PM$_{2.5}$ Ammonium Nitrate (NH$_4$NO$_3$) will be the focus of the project. The process of producing this simple compound is relatively complex, but general equation for production is well established, as shown in the equation below:

$$\text{NH}_3 (g) + \text{HNO}_3 (g) \Rightarrow \text{NH}_4\text{NO}_3 (s)$$

The ammonia (NH$_3$) is usually present in the ambient air, and is mostly the result of agriculture, especially livestock feces and fertilization. The nitric acid (HNO$_3$), however, is usually created through various atmospheric reactions, which are aided by low temperatures and photochemistry (sunlight) between nitrogen oxides (NO$_x$) and volatile organic compounds (VOC) (Stockwell et al., 2000). VOC is a category of organic chemical compound that is not typically extremely toxic but has chronic effects. The EPA regulates VOC in the land, water, and air. However, the relative contributions (i.e. which is the limiting reactant) of NO$_x$ and VOC to HNO$_3$, and ultimately, PM$_{2.5}$ production are not well known.
2.2.2 PM$_{2.5}$ Production vs. Levels

While PM$_{2.5}$ production is a reasonably complex process, it is also relatively simple to model, and in areas with an excess of ammonia, either VOC or NO$_x$ could be considered the limiting reactant in NH$_4$NO$_3$ production and thus a reliable proxy for PM$_{2.5}$ production (the reasons for choosing NO$_x$ for this report are explained a little later in Chapter 3). However, modeling the PM$_{2.5}$ levels is a far more difficult task, beyond the purview of this project and transportation engineers. Generally, the effects of weather and geography result in a very “noisy” data set for PM$_{2.5}$ levels. Different geographic features will allow for widely different PM$_{2.5}$ dissipation rates for different areas; everything else being equal. PM$_{2.5}$ levels will drop much faster on a flat plain than in a valley surrounded by mountains. Perhaps more importantly, even within a given area, PM$_{2.5}$ levels are highly dependent on weather patterns; wind speed and direction, air temperature and presence of inversions, sunny vs. overcast and precipitation, among other factors, all play a role in determining how much of the produced PM$_{2.5}$ will remain in the air and how concentrated it will become. As a result, even in a single location with constant PM$_{2.5}$ production rates, measured PM$_{2.5}$ levels could vary greatly from day to day, month to month, and even year to year.

2.2.3 PM$_{2.5}$ in Cache County

This section addresses the historical levels of PM$_{2.5}$ in Cache County and particular problems that the region faces. Note that this project takes a macro approach to the PM$_{2.5}$ levels, treating the entire valley as a single entity. While this is not entirely accurate, it is reasonable to consider PM$_{2.5}$ levels within the county to be part of a single system, and microscopic modeling of pollution levels is beyond the purview of this
project. However, for more a more detailed examination of PM$_{2.5}$ levels in Cache County, Utah State University performed a comprehensive air quality study in 2006 (Martin, 2006).

### 2.2.4 History of PM$_{2.5}$

Unfortunately, there is little data of PM$_{2.5}$ levels in Cache County before 2001, but both annual average and 24 hour 98$^{th}$ percentile standard levels are provided below in Table 1. The 98$^{th}$ percentile takes the top 2% and drops it off and takes the number of the 98$^{th}$ percentile. For example, if there are 100 days of data for level of pollution, the top 2 days are discarded then the 98$^{th}$ highest day is the number that represents the 98$^{th}$ percentile. This is done to cut out the unusually high days and then this is put into a 3 year average to cut down the unusually high or low years. The annual levels (not 3-year averages) are presented below in Figure 1. Figure 2 breaks down the average PM$_{2.5}$ level for the four targeted months of worse air quality of November through February and the months with better air quality of March through October and also the annual average (UDAQ, 2011).

#### Table 1: Historical PM 2.5 Levels in Cache Valley

<table>
<thead>
<tr>
<th>Year</th>
<th>Annual Average</th>
<th>24-hr 98$^{th}$ Percentile</th>
</tr>
</thead>
<tbody>
<tr>
<td>2001</td>
<td>15.56 mg/m$^3$</td>
<td>71.1 mg/m$^3$</td>
</tr>
<tr>
<td>2002</td>
<td>14.65 mg/m$^3$</td>
<td>58.4 mg/m$^3$</td>
</tr>
<tr>
<td>2003 (3-yr Avg)</td>
<td>8.27 mg/m$^3$ (12.8 mg/m$^3$)</td>
<td>31.5 mg/m$^3$ (54.7 mg/m$^3$)</td>
</tr>
<tr>
<td>2004 (3-yr Avg)</td>
<td>15.17 mg/m$^3$ (12.7 mg/m$^3$)</td>
<td>101.5 mg/m$^3$ (63.7 mg/m$^3$)</td>
</tr>
<tr>
<td>2005 (3-yr Avg)</td>
<td>12.95 mg/m$^3$ (12.1 mg/m$^3$)</td>
<td>56.7 mg/m$^3$ (63.2 mg/m$^3$)</td>
</tr>
<tr>
<td>2006 (3-yr Avg)</td>
<td>9.54 mg/m$^3$ (12.6 mg/m$^3$)</td>
<td>29.4 mg/m$^3$ (62.5 mg/m$^3$)</td>
</tr>
<tr>
<td>2007 (3-yr Avg)</td>
<td>9.46 mg/m$^3$ (10.7 mg/m$^3$)</td>
<td>35.2 mg/m$^3$ (40.4 mg/m$^3$)</td>
</tr>
<tr>
<td>2008 (3-yr Avg)</td>
<td>11.2 mg/m$^3$ (10.1 mg/m$^3$)</td>
<td>43.0 mg/m$^3$ (35.9 mg/m$^3$)</td>
</tr>
<tr>
<td>2009 (3-yr Avg)</td>
<td>10.1 mg/m$^3$ (10.3 mg/m$^3$)</td>
<td>44.0 mg/m$^3$ (40.7 mg/m$^3$)</td>
</tr>
<tr>
<td>2010 thru 2-28 (3-yr Avg)</td>
<td>--------------</td>
<td>40.6 mg/m$^3$ (42.5 mg/m$^3$)</td>
</tr>
</tbody>
</table>
Figure 1: Historical PM$_{2.5}$ Levels in Cache Valley

Figure 2: Average Monthly and Annual PM$_{2.5}$ Levels
As can be seen above in Table 1 and Figure 1, while the annual average levels are relatively smooth (though no definite trend can be determined), the 24-hour standard levels are exceedingly “noisy,” and thus difficult to model, especially given small data sets. Similar to climate change studies, in evaluating PM$_{2.5}$ levels, the natural variation from year to year can obscure the overall trends. Figure 2 shows the change of PM$_{2.5}$ levels from the inversion prone months from the rest. Ostro et al. (2006) found that an increase of 10 µg/m$^3$ of PM$_{2.5}$ correlate to an increased risk of mortality of 0.6%. Pope et al. (2002) reported and 8% increase in lung cancer for every 10 µg/m$^3$ increase of PM$_{2.5}$. It is clear that there is a difference in pollution levels and something needs to be done.

The EPA standard for 24-hour PM$_{2.5}$ was 65 µg/m$^3$ and 15 µg/m$^3$ for the annual standard which Cache County was usually a little lower than the standard with the exceptions of 2001 and 2004. Then in December of 2006 the EPA lowered the 24-hour standard to 35 µg/m$^3$ and kept the annual average the same, sending Cache County over the 24-hour limit. According to Utah Division of Air Quality (UDAQ) on December 14, 2009 Cache County was declared a nonattainment area by the EPA. If an area is designated nonattainment then the state must come up with a plan showing how the state will come into attainment of the standard. This plan has to be completed and approved by the EPA within three years and must show how the areas will reach the standard within five years after the plan is approved. The plan is called a State Implementation Plan (SIP) and must contain all strategies of what will be done to reduce the amount of PM$_{2.5}$ in the area (UDEQ, 2010a).
2.2.5 Special Challenges in Cache County

Though vehicle emissions are responsible for the vast majority of PM$_{2.5}$ production in Cache County, (UDEQ, 2010a) there is nothing inherently remarkable about the region’s vehicular traffic; many other places, especially dense urban areas, have greater VMT per land area and thus greater potential PM$_{2.5}$ production. What makes the air quality in Cache County so much worse than in other places, are its meteorological and topographical characteristics and the abundance of NH$_3$. The high mountains that surround the valley keep the particles from spreading outward, and the region’s weather patterns encourage frequent inversions during the winter months, which keep the particles from escaping upwards. Additionally, as a desert environment, Cache County often goes days, and even weeks, without receiving either rain or snow. This precipitation would act a giant filter, trapping the airborne particles and bringing them to the ground, but on dry days the PM$_{2.5}$ remains suspended in the air. Due to the wintertime inversions, and the fact that the reactions producing the HNO$_3$ precursor for PM$_{2.5}$ are encouraged by low temperatures, high PM$_{2.5}$ levels are a seasonal phenomenon. Whereas for three out of four seasons the region tends to experience relatively good air quality, during the winter months the PM$_{2.5}$ levels can skyrocket.

Over the past decade, the UDAQ, in collaboration with USU and local government officials, have implemented some reforms to reduce PM$_{2.5}$ levels, including increasing the coverage and ridership of Cache Valley Transit District (CVTD) buses, synchronizing signal timing to reduce idling vehicles, and instituting a green-yellow-red alert system to indicate air quality, with the information dissipated to the public via road signs, media, and internet (Utah Department of Environmental Quality, 2010b).
Importantly however, there are no required emissions testing for vehicles in Cache County.

2.2.6 Costs of PM 2.5 in Cache County

The total public health cost of PM$_{2.5}$ has not been calculated for all years, but as an indication, it was determined that in 2004 its financial impact in terms of deleterious health effects in Cache County was $6,524,000 (2010 dollars). Doctor Edward Redd from Bear River Health Department in Cache County did the calculations using values from EPA PM$_{2.5}$ criteria and using information in Cache County, with a breakdown as follows:

- 3 Deaths @ $2.1 million* $6,300,000
- 5 Hospitalizations @ $18,000 $90,000
- 109 ER/outpatient visits @ $240 $26,000
- 344 Asthma attacks @ $20 $7,000
- 200 follow-up visits @ $65 $13,000
- 300 extra prescriptions @$80 $24,000
- 400 sick days @ $160 $64,000

TOTAL $6,524,000

*EPA value for the value of life for people greater than 70 years old

Note that the above does not include the non-health costs of elevated PM$_{2.5}$ levels. Though harder to quantify, poor air quality days reduce general quality of life. It is less pleasant to live in an area of poor air quality, and people are less likely to go outdoors. This quality of life reduction could have numerous secondary effects, including reductions in property values (and thus property taxes), and decreased economic activity.
Further study and research would yield a better understanding of the total cost of elevated PM$_{2.5}$ levels in Cache County.

There are a number of different types of people that are at risk of airborne pollution, not only young and old people. Table 2 shows the total population and the number of people at risk from the pollution (American Lung Association, 2011). According to American Lung Association the percentage of people at risk in Cache County is 74.3%. Also, the grade given to Cache County is an F for the 24 hour particle pollution. With this many people at risk and the air as bad as it is there needs to be something done.

When the private cost of driving is less than the social cost because of an environmental impact then a Pigouvian tax needs to be assessed. A Pigouvian tax is a tax that is assessed when market activity, or in this case driving activity, creates negative externalities, like pollution for example. A true Pigouvian tax is meant to equal the negative externality and creates equilibrium between the private and social cost.

Table 2: People at Risk of Airborne Pollution in Cache County

<table>
<thead>
<tr>
<th>Total Population</th>
<th>Pediatric Asthma</th>
<th>Adult Asthma</th>
<th>Chronic Bronchitis</th>
<th>Emphysema</th>
<th>Cardiovascular Disease</th>
<th>Diabetes</th>
<th>Children Under 18</th>
<th>Adults 65 &amp; Over</th>
<th>Total</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>115269</td>
<td>2582</td>
<td>6320</td>
<td>3075</td>
<td>1246</td>
<td>23661</td>
<td>4328</td>
<td>35491</td>
<td>8905</td>
<td>85608</td>
<td>74.27</td>
</tr>
</tbody>
</table>

2.3 Toll Roads

Before any pricing scheme can be implemented the public has to accept it by seeing the benefit they will receive (Santos and Rojey, 2004, Eliasson, 2010, Lari and
Aultman, 2010, and Taylor et al., 2010). This can be done by educating the public to the problem that the pricing system addressed before addressing the pricing system itself. The way that the revenues from tolls are used greatly influences political acceptance (Santos and Rojey, 2004).

This section discusses some of the opportunities that road pricing has brought to other countries, as well as the United States. This section focuses on toll roads in general, give a background, and talk about different successes. Then there is a discussion of how technology provides opportunities for roadway pricing and greater efficiency for the driver. The section concludes with more of a focus on the successes of cordon pricing areas and how they lowered congestion and pollution.

2.3.1 Background

There are three ways to identify if a public good can be provided through privatization and be efficient and they are; incentives, information, and innovation (Boettke, 2010). In the presence of international success and the changes in technology, new opportunities are present which allow for greater benefit and less risk with private contracting. In the past, the problem with creating incentives was a knowledge problem. It was difficult to design contracts that instantiated the public control and purview of the public good as well as allow for the dynamic interaction of various market participants. Tolling technologies allow for an expanded set of opportunities.

New developments in pricing technology allow for greater flexibility. Because of this, government agencies can fulfill their various objectives while giving up some of the problems of administration better left to the experts. This allows for greater overlap between public goals and the collection of loose disaggregated information normally only
found in markets. Rather than seeing this as a threat to the missions of public agencies, this can be seen as an opportunity to correct for some of the greater fears of using markets without sacrificing the certainty of traditional public principles such as the reduction of environmental pollutants. In such a case the air quality in an area can be monitored, or as in certain areas of the country vehicle emissions can be monitored while the vehicles are in motion.

The other opportunity is the reduction in upfront costs. It was proposed that Pennsylvania’s Interstate 80 be converted into a toll road but because they anticipated large costs associated with tolling plazas and other types of monitoring of toll evaders, the plan was rejected in 2005 (Pennsylvania DOT, 2005). Since that time the technology has become even cheaper and new ways of monitoring have been perfected. Toll plazas are not even needed when license plate recognition technology is the norm. While these policies are by no means “hands-off” they do allow a greater use of contractors who can offer dynamic and innovative solutions to previously perplexing problems. The increased scope of cooperation between public and private agencies is promising new solutions for transportation funding.

In the United States and in Europe there is a successful legacy of publicly and privately owned toll roads spanning the last two centuries. In the 19th century, there was 10,000 miles of private toll roads in the United States and many more privately owned toll roads than publically owned. Early infrastructure was financed privately and led to economic booms in places like Albermarle County, Virginia (Majewski, 1996). The boom of rail transportation in the 19th and early 20th century caused the investment in private toll roads to slow. In the 1930’s, some states developed public toll road programs
because of the increased use of automobiles, the nonexistence of a major federal highway program, and the growing needs of commercialism (Fishbein, 1996).

In 1956, the Federal Aid Highway Act established a federal gas tax to help fund the interstate highway system, which in turn slowed the development of toll roads and increased the public role in the financing of roadways dramatically. The implementation of the interstate highway system caused a dramatic increase in vehicle miles traveled (VMT). Over time the increase in VMT has caused congestion in many metropolitan areas and some rural areas. From 1980 to 2000, VMT grew by 82% and the highway miles only increased by 4% as shown in Figure 3 (Poole, 2006). The dramatic increase in VMT in those years caused roadway infrastructure in many areas inadequate to meet the demands of the traveling public. This phenomenon led to increased interest in toll roads to provide additional capacity with the goal of congestion reduction.

Figure 3: Vehicle Miles Traveled and Roadway Lane Miles; (Source: Poole, 2006)
2.3.2 Roadway Pricing Successes

The use of roadway pricing has been beneficial in many places across the globe. Table 3 shows examples of successful toll roads from around the world. London, Stockholm, and Singapore have successfully utilized pricing to manage congestion and promote transit use. Benefits from the implementation of these programs include reduction in congestion and positive environmental impacts. When congestion pricing was introduced in central London in 2003, traffic congestion dropped about 30% and carbon emissions dropped about 15%. In 2005, the charge was increased to extract further benefits from the system and increase revenue (Larson, 2010). The net revenue of the London system is distributed 80% to improve transit and the other 20% to other transportation improvements within greater London (Doan, 2010).

<table>
<thead>
<tr>
<th>Location</th>
<th>Date Implemented</th>
<th>Average Toll Price (2 axle) per trip</th>
<th>Revenue (million)</th>
<th>Revenue Spending</th>
</tr>
</thead>
<tbody>
<tr>
<td>New Jersey Turnpike</td>
<td>1952</td>
<td>$9.05</td>
<td>$251.6 (2009)</td>
<td>Turnpike Maintenance &amp; Projects</td>
</tr>
<tr>
<td>Singapore</td>
<td>1975</td>
<td>$2.00</td>
<td>$72 (2008)</td>
<td>Transit &amp; Highway Systems</td>
</tr>
</tbody>
</table>
In Stockholm, a pricing scheme was tested for seven months and then voted on by the citizens and 51.7% were in favor. After the pricing was implemented, traffic volumes were decreased by about 25% and the net revenue was used for transit and building new roads. Also, the retail sales in stores in central Stockholm increased because more citizens bought locally to avoid the toll (Larson, 2010).

The New Jersey Turnpike is an example of tolls being used to build the road, maintain the road, and then improve it by adding lanes. After World War II, there was a need for a highway link through New Jersey but there was a shortage of capital funds to construct it. In order to build the turnpike bonds were issued and the roadway was constructed within two years. The result of this action is 122 miles of highway and one of the heaviest traveled roadways in the United States. It opened in 1952 with four lanes and expanded 83 miles of roadway in 1955 to six lanes. The innovative financing for the time made sure the roadway was built fast and the usage of the roadway pays off its debt with revenue gained and selling bonds to private companies (Nycroads, 2010).

Toll roads have been successful in all different parts of the world and help improve the local community by providing environmental benefits and reducing congestion and debt. The revenue helps improve the corridor in use as well as other transportation systems in surrounding areas.

2.3.3 Cordon Pricing

There are different types of road pricing schemes that have been implemented all around the world. There are areas where an entire roadway or bridge is tolled like the Chicago Skyway Bridge. There are areas where there is a lane or two that is dedicated to tolling like a High Occupancy Toll (HOT) lane. HOT lanes allow vehicles with more
than one person in them to use the lane or vehicles with only one person can use the lane if they pay a fee. Cordon pricing or area pricing sections off an area and then requires a fee to enter that area which requires a toll on all roadways entering the given area. There are three main locations that have had successful cordon pricing areas and will be discussed; London, Singapore, and Milan.

London has had its cordon pricing system in place since 2003 with an initial charge of 5 pounds (US $8) per vehicle per day, today the charge is 10 pounds (US $16). The main concern in London was congestion and the effects it was having. In section 2.3.2 it briefly discusses the effects of London’s cordon pricing around central London. To reiterate the effects of the congestion cordon pricing, the vehicle per kilometer decreased by 22% (Rotaris et al., 2010). Even though the main concern was congestion the environmental impacts of the cordon pricing area was a decrease in yearly emissions of carbon dioxide by 25%, particulate matter by 14%, nitrogen oxides by 7%, and carbon monoxide by 33% (Santos and Fraser, 2005).

London used automated number plate recognition (ANPR) software to track vehicles coming in and out of central London. The software reads the license plates with 90% accuracy rate. The time of the congestion charge is between 7 a.m. and 6:30 p.m. and each vehicle has the opportunity to register and pay the fee the day that they enter into the cordon area. They can either register before they enter, after they enter, or any time that day until midnight. At midnight the ANPR software checks all the images of vehicles that have been inside the cordon area against the vehicle registration numbers of vehicle that have paid. Then a record is kept of the entire unpaid vehicles and then a
manual check is done of those vehicles and a penalty charge notice is issued to the registered owner (Santos and Fraser, 2005).

London has a flat rate fee for entrance into pricing area. The area was initially 22 km² in 2003, and it was extended to the west to 40 km² in 2005 (Rotaris et al., 2010). It was later decreased to the original 22 km² at the beginning of 2011 because of political reasons. London has a number of vehicles that are exempt or may receive discounts from the fee. These vehicles are shown in Table 4 and taken from Santos and Fraser, 2005.

<table>
<thead>
<tr>
<th>Discount/status</th>
<th>Category</th>
</tr>
</thead>
</table>
| Fully exempt    | Motorcycles, mopeds and bicycles  
                 | Emergency vehicles  
                 | Public service vehicles with 9 or more seats licensed as buses  
                 | Vehicles used by disabled persons that are exempt from VED
                 | Licensed London taxis and minicabs |
| 100% discount with free registration | Certain military vehicles  
                                      | Local government service vehicles (e.g., refuse trucks, street maintenance)  
                                      | Vehicles with 9 or more seats not licensed as buses (e.g., community minibuses) |
| 100% discount with a one-off £10 registration | Vehicles driven for or by individuals or institutions that are Blue Badge holders
| 100% discount with £10 registration per year | Alternative fuel vehicles – requires emission savings 40% above Euro IV standards  
                                             | Roadside assistance and recovery vehicles (e.g., motoring organisations such as the Automobile Association) |
| 90% discount with £10 registration per year | Vehicles registered to residents of the central zone |

Notes:
- VED: Vehicle excise duty.
- Blue Badges, which existed before the scheme was implemented, are special parking permits issued to disabled people to allow them to park near shops, stations, and other facilities. The badge belongs to the disabled person who qualifies for it (who may or may not be a car driver) and can be used in any vehicle they are travelling in. The discount applies to individual Blue Badge holders anywhere in the EC.
- Unemployed 15-25 as a percentage of total unemployed (authors’ calculations on OECD data).
Table 4 shows the different vehicles that are exempt are the vehicles that the modal shift will head towards. Because there are certain vehicles that do not have to pay the fee the choice of mode will switch to those vehicles. This is illustrated in Table 5 which was also taken from Santos and Fraser, 2005.

Table 5: Percent in Change of Vehicles Entering and Exiting Condon Area

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Cars</td>
<td>-33%</td>
<td>-35%</td>
<td>-1%</td>
<td>-2%</td>
</tr>
<tr>
<td>Taxis</td>
<td>+17%</td>
<td>+8%</td>
<td>-1%</td>
<td>0%</td>
</tr>
<tr>
<td>Buses and Coaches</td>
<td>+23%</td>
<td>+21%</td>
<td>+8%</td>
<td>+4%</td>
</tr>
<tr>
<td>Vans</td>
<td>-11%</td>
<td>-15%</td>
<td>-1%</td>
<td>-1%</td>
</tr>
<tr>
<td>Lorries and other</td>
<td>-11%</td>
<td>-12%</td>
<td>-5%</td>
<td>-5%</td>
</tr>
<tr>
<td>Pedal Cycles</td>
<td>+19%</td>
<td>+6%</td>
<td>+8%</td>
<td>+8%</td>
</tr>
<tr>
<td>Powered Two-Wheeler</td>
<td>+12%</td>
<td>+5%</td>
<td>-3%</td>
<td>-4%</td>
</tr>
</tbody>
</table>

Table 5 shows that there was an increase in taxis, buses and coaches, pedal cycles, and power two-wheelers. This was because these vehicles were exempt from the fee and shows the modal shift that occurs with a cordon pricing scheme. Table 5 also shows that the percentage decrease of vehicles that enter and leave the vehicle is around the same percentage.

Singapore, like London, implemented a cordon pricing scheme to manage the high congestion. Singapore was the first cordon pricing ever implemented in the world back in 1975 with an Area Licensing Scheme (ALS). Singapore is a special case because the government has a history of trying to reduce congestion by levying a high premium on owning a vehicle. In 1972 the vehicle import tariff was raised from 30% to 45% and
then an additional registration fee of 25% of the market value of the vehicle had to be paid. Besides the vehicle tax, the government also imposed fuel taxes, ALS, Road Pricing Scheme, parking charges, Off-peak Car Scheme, and Vehicle Quota System (Goh, 2002).

With the ALS vehicles would have to buy a daily or monthly ALS license and display it when entering into the restricted zone. The area was 7 km$^2$ and vehicles were charged upon entry and exit. The scheme was enforced manually by police stationed at each entry point and they would write down the license plates of vehicles without proper ALS permits. When first implemented the traffic entering the restricted zone dropped by 45%, which exceeded the target of 25-35%, but by 1988 the drop was not sustained due to increase in employment in the central business district (Goh, 2002). This shows the level of difficulty when trying to estimate the reaction of the public.

Even though the ALS had a dramatic change in traffic volumes there were problems with the scheme. The problems included things like higher traffic volumes before and after restricted hours, paper scheme becoming out of date with the advancement of technology, and the amount of errors that occur with manual enforcement. In 1998 Singapore changed to Electronic Road Pricing. There was a new charging scheme that decreased the amount paid and was more efficient by using in-vehicle units with smart cards that are charged automatically upon entering the restricted area. If a vehicle does not have an in-vehicle unit or insufficient funds on the unit when entering a picture is taken of the back license plate and a fine is sent to the vehicle’s registered owner. The new scheme was enforce between 7:30 a.m. to 7 p.m. on central roads and from 7:30 a.m. to 9:30 a.m. on expressways and outer roads and price changes
according to time and location (Santos and Fraser, 2005). It reduced the enforcement personnel needed and the traffic volume on all monitored roads dropped by 17% (Goh, 2002). This change shows how the increase in technology has made road pricing more efficient and effective.

In 2008 Milan, Italy implemented a charging scheme to enter an 8 km$^2$ area at the center of the city. Unlike London and Singapore, which implemented a charging scheme to reduce congestion, Milan uses the charging scheme to reduce pollution. Because this is the purpose of this project, Milan will be looked at in detail and compared to Cache County. The name used to denote the pricing scheme in Milan is Ecopass, which summarizes the political objective of a pass to improve urban environment (Rotaris et al., 2010).

There is a public transport network that serves the whole Milan area, but road traffic is excessive and creates a lot of congestion and air pollution. Milan has one of the highest car concentrations in the world of 0.6 cars per inhabitant and 0.74 including all vehicles (Rotaris et al., 2010). With the people relying heavily on car use and with adverse geoclimatic conditions of Milan being in Po Valley, the result is very high pollution levels. Milan being in a valley is a similar situation that Cache County is in and is causing the same problems with pollution.

With the PM$_{10}$ concentration limit of 50 µg/m$^3$ in Europe, between the years 2002 and 2007, the limit was exceeded 125 days with an annual average of 51.2 µg/m$^3$ (Rotaris et al., 2010). Between the same years of 2002 and 2007 Cache County exceeded the PM$_{2.5}$ limit of 65 µg/m$^3$ from 2002 to 2005 and the limit of 35 µg/m$^3$ from 2006 to 2007 a total of 38 days. If the limit was a consistent 35 µg/m$^3$ during the years of 2002 and 2007
Cache County would have exceeded the limit 96 days and there is significant data missing from the winter months that would have made these number even higher (UDEQ, 2010a).

Milan has a history of drastic conditions to reduce traffic like traffic bans, free-of-cars Sundays, and even-odd plate regulations. With the implementation of the Ecopass in Milan between the hours of 7:30 a.m. and 7:30 p.m. vehicles are subject to a fee. Unlike London and Singapore that charge the fee based on time because of congestion, Milan changes fee based on 5 Euro emission standard classes shown in Table 6 and taken from Rotaris et al., 2010. They do this because it is a pollution based charge and not congestion based. To understand the definitions of each toll class in Table 6 the European emissions standard classification is provided in Table 7.

<table>
<thead>
<tr>
<th>Toll Classes</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class I</td>
<td>Liquid propane gas–methane–electric–hybrid</td>
</tr>
<tr>
<td>Class II</td>
<td>Gasoline Euro III, IV or more recent</td>
</tr>
<tr>
<td></td>
<td>Diesel Euro IV without anti-particulate filter (up to 30/06/08)</td>
</tr>
<tr>
<td></td>
<td>Cars and freight vehicles diesel Euro IV to more recent with anti-particulate filter</td>
</tr>
<tr>
<td>Class III</td>
<td>Gasoline Euro I and II</td>
</tr>
<tr>
<td>Class IV</td>
<td>Gasoline Euro 0</td>
</tr>
<tr>
<td></td>
<td>Diesel cars Euro I–III</td>
</tr>
<tr>
<td></td>
<td>Diesel goods vehicles Euro III</td>
</tr>
<tr>
<td></td>
<td>Diesel buses Euro IV and V</td>
</tr>
<tr>
<td>Class V</td>
<td>Diesel cars Euro 0</td>
</tr>
<tr>
<td></td>
<td>Goods vehicles Euro 0–II</td>
</tr>
<tr>
<td></td>
<td>Diesel buses Euro 0–III</td>
</tr>
</tbody>
</table>
Table 7: European Emissions Standard Classification

<table>
<thead>
<tr>
<th>Tier</th>
<th>Passenger Cars</th>
<th>Light Commercial Vehicles ≤ 1305 kg</th>
<th>Light Commercial Vehicles 1305-1760 kg</th>
<th>Light Commercial Vehicles &gt;1760 kg max 3500 kg</th>
<th>Large Goods Vehicles</th>
<th>Lorries and Buses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diesel</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Euro 0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Euro 3</td>
<td>Jan-00</td>
<td>Jan-01</td>
<td>Jan-01</td>
<td>Jan-01</td>
<td>1999-2005</td>
<td>Oct-00</td>
</tr>
<tr>
<td>Euro 4</td>
<td>Jan-05</td>
<td>Jan-06</td>
<td>Jan-06</td>
<td>Jan-06</td>
<td>2005-2008</td>
<td>Oct-05</td>
</tr>
<tr>
<td>Euro 5</td>
<td>Jan-09</td>
<td>Sep-09</td>
<td>Sep-10</td>
<td>Sep-10</td>
<td>2008-2012</td>
<td>Oct-08</td>
</tr>
<tr>
<td>Gasoline</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Euro 0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Euro 2</td>
<td>Jan-96</td>
<td>Jan-98</td>
<td>Jan-98</td>
<td>Jan-98</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Euro 3</td>
<td>Jan-00</td>
<td>Jan-01</td>
<td>Jan-01</td>
<td>Jan-01</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Euro 4</td>
<td>Jan-05</td>
<td>Jan-06</td>
<td>Jan-06</td>
<td>Jan-06</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Euro 5</td>
<td>Jan-09</td>
<td>Sep-09</td>
<td>Sep-10</td>
<td>Sep-10</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

In Table 7 each different classification of vehicle has to pass a different emission standard. Milan used the toll classes shown in Table 6 to assess the charge differentiation. The first two classes are exempt from the toll because they do not emit enough pollution to be taxed. Then the next three classes, III through V, have different charges with a range differentiation of about 8 Euros which is relatively high considering Stockholm has a differentiation of about 1 Euro (Rotaris et al., 2010). Also, Milan created rebates to make the scheme more acceptable by the public. The rebates consist of a 50% rebate upon the first 50 entries into the toll area and then 40% rebate for the next 50 entries within a year. After the first 100 entries within a year, full price is charged. Residents are also given the opportunity to buy a yearly pass. The tolls for each class and discounts are shown in Table 8 taken from Rotaris et al., 2010.
Table 8: Ecopass Toll Rates (in Euros)

<table>
<thead>
<tr>
<th>Toll Classes</th>
<th>Daily Charge</th>
<th>Discounted multiple entries (max 100 entries per year)</th>
<th>Yearly pass for residents</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>50% Rebate (first 50 entries) 40% Rebate (successive 50 entries)</td>
<td></td>
</tr>
<tr>
<td>Class I</td>
<td></td>
<td>Free</td>
<td></td>
</tr>
<tr>
<td>Class II</td>
<td></td>
<td>Free</td>
<td></td>
</tr>
<tr>
<td>Class III</td>
<td>2</td>
<td>50</td>
<td>60</td>
</tr>
<tr>
<td>Class IV</td>
<td>5</td>
<td>125</td>
<td>150</td>
</tr>
<tr>
<td>Class V</td>
<td>10</td>
<td>250</td>
<td>300</td>
</tr>
</tbody>
</table>

Table 8 shows that vehicles that produce more emission pollution are charged more and the vehicles that emit little pollution are exempt from the toll. Because of this there was a modal shift to vehicles that were exempt from the toll. Cache County could implement a similar plan to tax the vehicles that pollute more to cause people to shift their mode of transportation to vehicles that pollute less or to public transit. In Table 9 it shows the modal shift from classes III-V to the exempt classes I and II taken from Rotaris et al., 2010.
Table 9: Vehicle Class Change after Toll Implementation (vehicles/day)

<table>
<thead>
<tr>
<th>Class</th>
<th>Before Ecopass scheme</th>
<th>After Ecopass scheme March 2008</th>
<th>Variation</th>
<th>Before Ecopass scheme</th>
<th>After Ecopass scheme March 2008</th>
<th>Variation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class I</td>
<td>1105</td>
<td>1918</td>
<td>813</td>
<td>92</td>
<td>410</td>
<td>317</td>
</tr>
<tr>
<td>Class II</td>
<td>50,993</td>
<td>53,088</td>
<td>2095</td>
<td>3399</td>
<td>4043</td>
<td>644</td>
</tr>
<tr>
<td>Class III</td>
<td>11,898</td>
<td>5960</td>
<td>−5939</td>
<td>356</td>
<td>494</td>
<td>138</td>
</tr>
<tr>
<td>Class IV</td>
<td>20,992</td>
<td>7535</td>
<td>−13,457</td>
<td>6653</td>
<td>3917</td>
<td>−2737</td>
</tr>
<tr>
<td>Class V</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2674</td>
<td>1638</td>
<td>−1036</td>
</tr>
<tr>
<td>Total</td>
<td>84,988</td>
<td>68,500</td>
<td>−16,488</td>
<td>13,174</td>
<td>10,500</td>
<td>−2674</td>
</tr>
</tbody>
</table>

As can be seen from Table 9 the cars entering the area decreased by 19.4% and the freight vehicles entering the area decreased by 20.3%. The numbers increased for classes I and II but overall there was a decrease in vehicle entering. Because of this decrease and modal change there was a reduction in air emissions of 18% of the total \( \text{PM}_{10} \), 17% of \( \text{NO}_x \), and 14% of \( \text{CO}_2 \). Even though the number of tolled vehicles in Milan is about 20% less than those in London and 18% less than those in Stockholm the results are similar (Rotaris et al., 2010).

The literature review done on the pollution in Cache County validates the need for the study when the EPA declared Cache County a nonattainment area. The review done on tolling and cordon pricing will be used in the modeling in Cache County. The reductions found in London, Milan, and Stockholm are 22% vehicle-km, 20% vehicles...
entering daily, and 23.8% number of entries, respectively. Although these are three different measurements they are all similar in magnitude of traffic reductions (Rotarisi et al., 2010). In Singapore they also experienced a 17% drop in traffic volume after implementing their electronic road pricing scheme. Table 10 shows a summary of the different cordon areas and their impact on traffic.

Table 10: Summary of Cordon Pricing Areas

<table>
<thead>
<tr>
<th>City</th>
<th>Size (km²)</th>
<th>Population (millions)</th>
<th>Toll</th>
<th>Technology</th>
<th>Impacts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Milan</td>
<td>8</td>
<td>3.7</td>
<td>2-10 (Euros) (US $3-14)</td>
<td>Automatic number plate recognition</td>
<td>20% reduction (vehicles entering daily)</td>
</tr>
<tr>
<td>London</td>
<td>22</td>
<td>7.5</td>
<td>10 (Pounds) (US $16)</td>
<td>Automatic number plate recognition</td>
<td>22% reduction (vehicle-km)</td>
</tr>
<tr>
<td>Singapore</td>
<td>7</td>
<td>4.5</td>
<td>0.60-20 (Singapore Dollars) (US $0.50-16)</td>
<td>Electronic road pricing</td>
<td>17% reduction (traffic volume)</td>
</tr>
<tr>
<td>Stockholm</td>
<td>47</td>
<td>0.85</td>
<td>10-60 (Kronor) (US $1.50-9)</td>
<td>Automatic number plate recognition</td>
<td>23.8% reduction (number of entries)</td>
</tr>
</tbody>
</table>

A similar number of reductions will be used in the Cache County model in this project and will be a 20% reduction of vehicle trips entering cordon area to be comparable to the numbers shown above. The modeling will not deal with the price of the toll but rather the effect a toll has on the reduction of VMT and pollution. In the cases of London, Milan, and Stockholm they all had different toll prices, populations, and
area sizes, but all had similar results. Also, the numbers shown in Table 5 of the percentage of vehicles leaving and entering the cordon area in London are very similar. Because of this the number of vehicle miles travelled in the model for Cache County will have the same reduction of 20% for both vehicles entering and exiting the network.
3.1 Introduction

The study and program that provides the data for this project was provided by Cache Metropolitan Planning Organization (CMPO) in software called CUBE Base and Voyager. This chapter describes the methodology used in CUBE Voyager to generate the model of Cache County. Then this chapter explains the methodology of what was taken from the model and then changed to represent a cordon area pricing. Then the output from the model was then used to calculate pollution. For this methodology there were a number of different assumptions made and those are discussed and justified.

3.2 CMPO CUBE Base and Voyager Model

CUBE Voyager is software developed by Citilabs that is used to forecast personal travel through a four-step process. The four-step process includes Trip Generation, Trip Distribution, Mode Choice, and Traffic Assignment, which will be discussed in detail. The software is origin and destination based travel from different zones. These steps will be discussed in detail later. The initial Cache Travel Demand model was developed in 1998 using data that had been collected from a household trip diary survey, an external origin-destination study, and a speed study in 1996. The model was then updated again in 2006 to a base year of 2004. Included in this were updated socioeconomic data and an updated roadway network.

After the development of the 2006 model a Transportation Model Improvement Program (TMIP) peer exchange highlighted strengths and weaknesses in the model for
future improvements. Future changes were then planned to implement the most important recommendations for the next version of the model. The primary motive for updating the model related to the development of a better planning tool for future projects and to provide an analysis tool to assist in the EPA air quality compliance.

The CMPO contracted Resource System Group, Inc. (RSG) to deal with the problems and develop the model. The model was completed but because of lack of funding there is not a complete documentation of the model. The information discussed in this chapter was taken from the documentation given to the CMPO from RSG and also information taken directly from the model itself.

3.2.1 Model Design and Structure

The algorithms used in the CMPO Travel Demand model were from Citilabs’ CUBE Base and Voyager software and used to execute its data processing and to interact with the data. The model software platform is similar to other models in Utah that use the same software developed by Citilabs. The model is designed with three directories: the input directory, the model script directory, and the output directory. An example is show below in Figure 4, taken from RSG. The inputs directory contains all the necessary data to run the model. The model script directory contains all the scripts, applications, and instructions necessary to run the model. These files tell the software how to use the input data and how to visualize the model in CUBE. The output directory contains all the results from the different scenarios.
3.2.2 Inputs

Because of the complexity of the model all the inputs were kept the same as the model used for the CMPO. However, to understand what the model is computing the inputs are described below. The input directory contains all the information needed to run the model. The input data includes traffic analysis zones (TAZ), socioeconomic data, highway network, transit network, college trip model inputs, and external trips.
Traffic Analysis Zones

The TAZ boundaries were made based on proposed 2010 Census block, block group and tract geography, highway network, and land use. There are 310 internal zones and 7 external zones in the model. Figure 5 shows the 310 zones in the network and the external zones are indicated with numbers 394 to 400.
Zonal activity is the basis of the software because each zone is a trip producer and attractor. Within the model, trip making from zone to zone is assumed to begin/end at the zone centroid. The entire model is made up of links (e.g. roads) and nodes with centroids within each zone, an example is shown in Figure 6 below.

Figure 6: Example of TAZ in a Network
The TAZs were aggregated to create large and medium districts based on cities and towns. This was done according to MPO planning boundaries and the medium districts are found within the large districts. Figures 7 is a map that shows the boundaries of the large and medium districts and Table 11 describes each district, both were taken from the RSG report. There are 17 medium districts and 7 large districts.

Figure 7: Map of Large and Medium Districts
Table 11: Description of Large and Medium Districts

<table>
<thead>
<tr>
<th>DISTLRG</th>
<th>Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>North County</td>
<td>Clarkston, Cornish, Lewiston, Trenton, and Richmond</td>
</tr>
<tr>
<td>2</td>
<td>West County</td>
<td>Newton, Amalga, and Mendon</td>
</tr>
<tr>
<td>3</td>
<td>North MPO</td>
<td>Smithfield and Hyde Park</td>
</tr>
<tr>
<td>4</td>
<td>Central MPO</td>
<td>North Logan and Logan</td>
</tr>
<tr>
<td>5</td>
<td>South MPO</td>
<td>River Heights, Providence, Millville, Nibley, and Wellsville</td>
</tr>
<tr>
<td>6</td>
<td>South County</td>
<td>Paradise</td>
</tr>
<tr>
<td>7</td>
<td>Mountain</td>
<td>Mountains</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>DISTMED</th>
<th>Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Clarkston</td>
<td>Clarkston</td>
</tr>
<tr>
<td>2</td>
<td>Cornish to Trenton</td>
<td>Cornish, Lewiston, and Trenton</td>
</tr>
<tr>
<td>3</td>
<td>Richmond</td>
<td>Richmond</td>
</tr>
<tr>
<td>4</td>
<td>Newton</td>
<td>Newton</td>
</tr>
<tr>
<td>5</td>
<td>Amalga</td>
<td>Amalga</td>
</tr>
<tr>
<td>6</td>
<td>Mendon</td>
<td>Mendon</td>
</tr>
<tr>
<td>7</td>
<td>Young Wood</td>
<td>Young Wood</td>
</tr>
<tr>
<td>8</td>
<td>Smithfield</td>
<td>Smithfield</td>
</tr>
<tr>
<td>9</td>
<td>Hyde Park</td>
<td>Hyde Park</td>
</tr>
<tr>
<td>10</td>
<td>North Logan</td>
<td>North Logan</td>
</tr>
<tr>
<td>11</td>
<td>Logan</td>
<td>Logan</td>
</tr>
<tr>
<td>12</td>
<td>River Heights to Nibley</td>
<td>River Heights, Providence, Millville, and Nibley</td>
</tr>
<tr>
<td>13</td>
<td>Hyrum</td>
<td>Hyrum</td>
</tr>
<tr>
<td>14</td>
<td>Wellsville</td>
<td>Wellsville</td>
</tr>
<tr>
<td>15</td>
<td>West Paradise</td>
<td>West Paradise</td>
</tr>
<tr>
<td>16</td>
<td>Paradise</td>
<td>Paradise</td>
</tr>
<tr>
<td>17</td>
<td>Mountains</td>
<td>Mountains</td>
</tr>
</tbody>
</table>

**Socioeconomic Data**

The units for the socioeconomic data set in the model are households, household population, seven employment categories (2 retail, 2 industrial, and 3 other), and income. Each TAZ in the model has number of households, population, and total employment. The socioeconomic data was developed with the Governor’s Office of Planning Budget (GOPB) forecasts for county-level and employment totals. The totals are used as one of
the base inputs to control the model’s socioeconomics. GOPB has a 2008-baseline projections give the county’s socioeconomic totals from 2000 to 2060 are used in the model. The model uses households and household population as residential controls for TAZ. Figure 8 shows the GOPB residential controls used in the model and how they change from year to year, taken from RSG report.

![Figure 8: GOPB Residential Control Totals](image-url)
For employment the GOPB divides the data into 23 categories and then puts those categories into 7 employment classifications. Table 12 shows the employment classifications with each of the 23 categories in them, taken from RSG report. All employment in Cache County is represented in Table 12.

Table 12: GOPB Employment Data Classification

<table>
<thead>
<tr>
<th>Employment Classification</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ret3</td>
<td>Retail Trade</td>
</tr>
<tr>
<td>Ret5</td>
<td>Accom, Food Services</td>
</tr>
<tr>
<td>Ind1</td>
<td>Forestry, Fishing, Mining, Utilities, Manufacturing</td>
</tr>
<tr>
<td>Ind2</td>
<td>Wholesale Trade, Transp, Warehousing</td>
</tr>
<tr>
<td>Oth1</td>
<td>Construction, Information, Real Estate, Leasing, Profess, Tech Services, Mngmt of Co, Enter, Admin, Waste Services, Farm</td>
</tr>
<tr>
<td>Oth2</td>
<td>Education Services, Health Care, Social Asst, Arts, Enter, Rec, Other Services(excl Gov), State &amp; Local Gov, Fed Civilian &amp; Military</td>
</tr>
<tr>
<td>Oth4</td>
<td>Finance, Insurance</td>
</tr>
</tbody>
</table>

In the CMPO model 4.5% of total employment is discarded and not used in the model to account for home-based jobs. The GOPB projected each employment classification for the year of 2000-2060 with 2008 as a baseline. This projection is shown in Figure 9 and was taken from RSG report.
In Figure 9 most people are employed by Oth2 which has Education Services category and shows that most people in Cache County are employed by the University. There is a big gap and then Oth1 is the next highest employment which has Farm category in it shows the high amount of farmers in the county.

The residential and employment data controls from the GOPB were used to distribute the data into the TAZ. The residential data was distributed by taking households and household population from the 2000 Census block data and controlling to the 2000 GOPB county household and population totals. Then parcels and building permit data was used to locate new households between 2000 and 2008. The employment data was distributed by using the Utah Department of Workforce Services 2008 data to locate the base year employment at the TAZ level. Then the data was
converted to a GOPB data with expansion factors by the seven employment classifications.

Income was also used in the input data for the model. Median household income for the CMPO model was taken from the 2000 Census. The Census Bureau aggregates income data at Census tract level, which are relatively permanent statistical subdivisions of a county. TAZ within the border of a certain Census tract receives that tract’s median household income.

**Highway Network**

The input highway network for the CMPO model is a “master” network. The network is made up of a number of links and nodes. The master network contains fields like functional type and lanes for each link and node. From the master network, other scenarios can be run easier because there is a consistent structure for the links and nodes. Because Cache County is a nonattainment area they have to show that any improvements or changes cannot increase the current level of PM$_{2.5}$. In the CMPO model there are three scenarios that are run, which consist of the three phases put in the Cache County, Utah Regional Transportation Plan 2035. There are a total of 2,056 nodes and 3,291 links in the base year of 2008 and each has its own attributes. The attributes includes things like length, street name, zone number, excreta. A snap shot of the network taken from the model is shown in Figure 10.
Transit Network

The local transit network was added to the CMPO model to increase the number of modes that can be taken within the network. All 15 bus routes are accounted for, and peak and off-peak period departures frequencies were calculated separately for each route. Local bus routes were coded to stop at each highway node along bus routes to allow people to get on the bus at each stop, which is not completely accurate because the buses do not stop at every intersection. The express bus routes were coded as non-stop according to the CVTD schedules.
College Trip Model Inputs

Because Utah State University (USU) is such a big attraction for college students in Cache County, a college student distribution model was included in the CMPO model. This distribution uses a student base-year distribution and a year-by-year enrollment control total for the input data. The base-year distribution was developed based on a sample of the USU student enrollment from the Fall semester of 2008. The sample had 7,974 addresses that were geo-coded as point shape file by the CMPO and then joined to the model’s TAZ and scaled to the 2008 Fall enrollment of 17,550. The sample distribution represents the student population fairly well because the majority are concentrated around the University with the rest spread out around the county as shown in Figure 11, taken from RSG report.

Figure 11: USU Student Distribution from Fall 2008
The year-by-year enrollment control total was obtained from the Utah System of Higher Education 2008 long-term enrollment projection. The projection had both historic data from 1988 to 2007 and forecasted student enrollment date from 2008 to 2027. Then because the CMPO model goes to the year 2040 the years from 2028 to 2040 were extrapolated from the given data.

**External Trip Table**

The CMPO model estimates trips for origin and destination that lie within Cache County. However, a considerable number of trips have at least one end outside Cache County. These trips are known as “external” trips and have three classifications. The three classifications are: internal to external trips (IX), external to internal trips (XI), and external to external trips (XX). IX trips are produced in Cache County and are attracted to somewhere outside of Cache County. XI trips are produced outside of Cache County and then attracted to Cache County. XX trip are trips that simple pass through Cache County. These trips were calculated using Utah Department of Transportation traffic counts around the county lines. To determine the future external trips the historical growth trends were used. The external trips will be the focus of the project to assess a toll on vehicles entering, leaving, and passing through Cache County.

**3.2.3 Trip Generation**

With all of the inputs in place there is a four-step travel forecasting process to use all the data, the first step is Trip Generation. It relates the intensity of trip making to land use and the socioeconomic characteristics. It also provides a measure of travel frequency, yielding a total volume of trips defined in a certain region at a certain time.
Each zone has different activities that can either produce and/or attract trips. Each trip is classified by a trip purpose.

In the CMPO model there are six trip purposes and they are; home base work trips (HBW), home base commercial trips (HBC), home base other trips (HBO), non-home base trips (NHB), external trips (EXT), and commercial attraction (COMM). HBW are trips that are produced from a residential zone and attracted to a work zone. HBC are trips that are produced from a residential zone and attracted to commercial zone. HBO are trips that are produced from a residential zone and attracted to any other type of zone besides a work zone. NHB trips are produced from anywhere that is non-home based zone and is attracted to a non-home based zone like going from work to a store, for example. EXT are trips that are entering into the network, leaving the network, or passing through the network and will be the focus of the modeling. COMM trip is only for trip attraction and does not produce any trips in the model. USU trips are calculated separately and put into the total attractions. The CMPO model used a regression equation for all productions and attractions.

3.2.4 Trip Distribution

The second step in the four-step travel forecasting process is Trip Distribution. This step calculates how many trips from a given origin will end up at a given destination. Things that affect the distribution are things like the amount of trips and travel impedances like travel time, travel cost, and distance. Trip distribution takes the production and attraction estimates from the Trip Generation step and the impedances to calibrate the trip distribution model. The analysis time period for the model is one day broken down into four time periods of AM (3 hours), Mid Day (6 hours), PM (3 hours),
and Evening (12 hours). An origin/destination matrix is created that shows the number of trips going from one zone to another. The CMPO model uses a doubly constrained gravity model based on trip purposes. The model uses AM time to distribute HBW trips, and uses the average off peak and AM peak to distribute HBO, NHB, and COMM trips.

3.2.5 Mode Choice

The third step in the four-step travel forecasting process is Mode Choice. This step takes the trip distribution from zone to zone and breaks those trips up into different modes of travel. The CMPO model includes both motorized and non motorized modes. The motorized modes include: auto, bus, walk + bus, and drive + bus. The non motorized modes are walk and bike. The assumption in selecting a mode is that the traveler will select the mode that gives them the most utility. The CMPO model used a nested logit model to decide which mode of travel will be taken.

3.2.6 Traffic Assignment

The final step in the four-step travel forecasting process is Traffic Assignment. The decisions in this step are primarily a function of route travel time that is determined by traffic flow. The model is calibrated to the AM, Mid Day, PM, and Evening periods. The assignment is calculated using equilibrium assignment which has a perfect balance of travel demand and travel supply. Two main assumptions are made when developing user equilibrium. It is assumed that travelers will only select routes based on route travel times and also that the travelers know all the travel times on all the available routes. This means that the traveler will find the route with the lowest travel time from origin to destination. When the system is in equilibrium no traveler will gain from changing paths.
In the Traffic Assignment step it changes the production and attraction person trips to origin and destination vehicle trips. The number of vehicle trips will be the only portion of the model that will be modified. A screen shot of the traffic assignment in the model is shown in Figure 12. The traffic assignment step is called Highway Assignment in the CMPO model.

The reduction of external trips in this section will change with each scenario in the next chapter. Each matrix made has 310 internal zone and 7 external zones. An example of the matrix format is shown in Figure 13.
This matrix is created by the program and only the external parts of the matrix will be changed. This will symbolize the cordon area around Cache County and will regulate the people entering and leaving the county. The reductions will be made by changing the script in the model.

3.2.7 Model Outputs

The CMPO model gives outputs for each scenario in vehicle miles travelled (VMT) and vehicle hours travelled (VHT). The VMT and VHT is broken down into four time periods of PM, MD, PM, and EV. Then each of those periods are broken down into freeway, ramp, arterial, and local roadways. Then each roadway type is broken down into fourteen speed categories. The model output used to calculate the pollution level is the VMT and will be discussed in detail of why and how it is used in the following sections.
3.3 Pollution Modeling

This section discussed how the output of the CMPO demand model will be used to measure the reduction in pollution due to a cordon area pricing scheme in Cache County. It will state the measures taken and assumptions and justifications of the modeling.

3.3.1 MOBILE6.2

MOBILE6.2 was software used by the EPA to estimate emission rates for vehicles. MOBILE6.2 has been replaced by MOVES as EPA’s official model for estimating emission. However, CMPO still uses MOBILE6.2 and used it for the Cache Air Quality Memorandum which includes all capacity increasing transportation projects until 2035. Because Cache County was declared a non-attainment area by the EPA they have to prove that any capacity increasing projects will not increase the current pollution level of PM$_{2.5}$. Currently, Cache County has three phases of construction of capacity increasing projects found in the Regional Transportation Plan that have to be proven to not increase the pollution (CMPO, 2011).

Phase I is included in the years of 2011 to 2020 and has nine highway capacity projects that have a total highway funding of $195,134,243. Phase II will take place during the years of 2021 to 2030 and has nine highway capacity projects that have a total highway funding of $293,824,404. The final phase, Phase III, is from years 2031 to 2035 and has four projects that total $228,036,280 of highway funding. There is a Phase IV that has fifteen unfunded highway capacity projects. All three phases are included in the CMPO demand model to model the impact of the projects and will be included in the analysis.
CMPO uses a number of different inputs to get the emissions rate from MOBILE6.2. They use two different emissions to relate to PM$_{2.5}$ emissions both direct emissions (primary) and precursor (secondary) emission. In the Cache Air Quality Memorandum 2011 primary emissions consist of particles emitted from vehicle exhaust (elemental carbon, organic carbon, gasoline particle matter, and SO$_4$), brake wear, and tire wear. A secondary emission of PM$_{2.5}$ refers to the vehicle exhaust emissions of gaseous nitrogen oxides (NO$_x$) that changes in the air to a particulate form through chemical reactions. Table 13 shows both the emissions for NO$_x$ secondary and primary PM$_{2.5}$ emissions. These emissions rates are used in the modeling to calculate the amount of pollution.

Table 13: Emissions Rates

<table>
<thead>
<tr>
<th>Year</th>
<th>2010</th>
<th>2020</th>
<th>2030</th>
<th>2035</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Secondary emissions rate (grams/mile)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NOx</td>
<td>1.742</td>
<td>0.826</td>
<td>0.595</td>
<td>0.578</td>
</tr>
<tr>
<td><strong>Primary PM2.5 emissions (grams/mile)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ec (diesel elemental carbon)</td>
<td>0.0090</td>
<td>0.0016</td>
<td>0.0008</td>
<td>0.0006</td>
</tr>
<tr>
<td>Oc (diesel organic carbon)</td>
<td>0.0054</td>
<td>0.0010</td>
<td>0.0006</td>
<td>0.0004</td>
</tr>
<tr>
<td>Gpm (gasoline particles)</td>
<td>0.0078</td>
<td>0.0068</td>
<td>0.0068</td>
<td>0.0068</td>
</tr>
<tr>
<td>Pbr (brake wear particles)</td>
<td>0.0106</td>
<td>0.0106</td>
<td>0.0106</td>
<td>0.0106</td>
</tr>
<tr>
<td>Pti (tire wear particles)</td>
<td>0.0044</td>
<td>0.0044</td>
<td>0.0044</td>
<td>0.0040</td>
</tr>
<tr>
<td>SO4 (sulfate particles)</td>
<td>0.0010</td>
<td>0.0010</td>
<td>0.0010</td>
<td>0.0010</td>
</tr>
<tr>
<td>Total direct PM2.5 emissions</td>
<td>0.0382</td>
<td>0.0254</td>
<td>0.0242</td>
<td>0.0234</td>
</tr>
</tbody>
</table>
The emissions rate goes down because MOBILE6 takes into account the ongoing improvements in vehicle engine standards, which means that older vehicles are taken off the road or fixed and newer ones are put on. The vehicle fleet average is the limiting factor in the model in the case of Cache County. As the population goes up with each demographic each year the emissions rate has a huge drop off at the beginning because the older more polluting vehicles “in theory” should be fixed or break down. Then the amount of drop of in emissions decreases every time because once the network reaches capacity the fleet average will not be the limiting factor, the population will be.

3.3.2 Assumptions and Justification

This section will examine the various assumptions made in this report and provide justification. Importantly, this report is concerned with the transportation component of PM$_{2.5}$ production, and it is hoped that addition work by environmental researchers will help provide the planning committee with a more complete view of the problems facing the region.

**Using NO$_x$ as a Proxy for PM$_{2.5}$ Production**

As explained in section 2.2.1, the three major components that lead to PM$_{2.5}$ production are NH$_3$, NO$_x$, and VOC. Whichever factor is the limiting reactant is the one that will determine eventual PM$_{2.5}$ production. As an agricultural region, Cache County has a surplus of NH$_3$, so that any increase or decrease in NH$_3$ will have no appreciable effect on PM$_{2.5}$ production (Martin, 2006). However, as the relative contributions of VOC and NO$_x$, are less well known, it is impossible to determine which of the two the limiting reactant is. Different agencies and different groups have used one or the other as proxies for PM$_{2.5}$. The Wasatch Front Regional Council (whose jurisdiction includes Salt
Lake City, UT) uses VOC, while the CMPO uses NO\textsubscript{x}. To provide consistency for examination of Cache County, this report also uses NO\textsubscript{x}. Note however, that the distinction is not as great as it first appears. Any efforts taken to reduce NO\textsubscript{x} will also reduce VOC, so based on the current understanding of the atmospheric chemistry, either would be acceptably proxies for PM\textsubscript{2.5} production.

**Assuming Vehicular NH\textsubscript{4}NO\textsubscript{3} to Comprise All of PM\textsubscript{2.5} Production**

As discussed in section 2.2.1, all the chemical reactions between VOC, NO\textsubscript{x}, and NH\textsubscript{3} ultimately yield ammonium nitrate (NH\textsubscript{4}NO\textsubscript{3}). Whereas vehicles produce other forms of forms of PM\textsubscript{2.5}, ammonium nitrate makes up the majority. For example, in the 2010 prediction for Cache County, primary vehicular PM\textsubscript{2.5} production (such as through brake and tire particulates) is only 0.0591 tons/day, as compared to NO\textsubscript{x} emissions of 5.39 tons/days (CMPO, 2011). While the complex chemistry precludes a true 1:1 comparison of these two values, the actual value is likely to be somewhat close; while all NO\textsubscript{x} is not converted to NH\textsubscript{4}NO\textsubscript{3}, the greater mass of the later means that a 1:1 chemical reaction would result in a greater than 1:1 ratio of masses. Since primary vehicular PM\textsubscript{2.5} production (by mass) is only 1.1% of the NO\textsubscript{x} emissions, this report follows the convention of numerous planning agencies and PM\textsubscript{2.5} researchers, assuming for planning purposes that all vehicular PM\textsubscript{2.5} production is ammonium nitrate, for which NO\textsubscript{x} is used as a proxy.

The focus only on vehicular PM\textsubscript{2.5}, as opposed to total PM\textsubscript{2.5} is not always appropriate, but it is applicable in Cache County. The region lacks much heavy industry or major power plants that would produce PM\textsubscript{2.5}. It does have a small diesel-power secondary power plant to supply electricity in times of high demand, but it only tends to
be turned on in the summer, when PM\textsubscript{2.5} levels are less of a concern, and overall it provided negligible contributions. USU had a coal-fired heating plant but it was replaced with a modern natural gas plant. Currently the majority of PM\textsubscript{2.5} in Cache County can be attributed to vehicle emissions (UDEQ, 2010a). Non-vehicular emissions are not predicted to vary much over time, so can be considered a constant background to vehicular PM\textsubscript{2.5} production. However, any future additions of major non-vehicular emitters, such as a coal-powered electricity plant, would obviously necessitate a re-evaluation of this assumption. However, considering the existing PM\textsubscript{2.5} problems in the regions, building any such large-scale emitters would not be recommended.

**Focus on PM\textsubscript{2.5} Production as Opposed to Levels**

As discussed in section 2.2.2, modeling future PM\textsubscript{2.5} levels, especially the 24-hour 98\textsuperscript{th} percentile standard is notoriously difficult, as it effectively demands predicting the weather years into the future. As a result, most PM\textsubscript{2.5} research, including this project, are by necessity forced to evaluate future PM\textsubscript{2.5} production, which can be reasonably accurately modeled. However, some comparisons must be made between the two in order to answer the question of “what level of PM\textsubscript{2.5} production will result in acceptable PM\textsubscript{2.5} levels?” Unfortunately, there is not even an agreement on what is the desired 24-hour standard level or even if that is the most important standard. For the 24-hour standard, which despite all the unknowns is generally considered to be the most important standard, most researchers agree that exceeding the government level of 35 $\mu$g/m\textsuperscript{3} indicates an acute problem. Anything under 35 $\mu$g/m\textsuperscript{3} would be considered a major success because that would pass the standard set by the EPA. Since the three-year averages for the 24-hour standard in recent years have approximated 40 $\mu$g/m\textsuperscript{3} (see Table
1), a 12.5% reduction in PM$_{2.5}$ levels (from the 2010 base year) can be seen as desirable. Correspondingly, this paper will set a provisional goal of a 12.5% reduction in PM$_{2.5}$ production. However, less important that the actual desired percent reduction is the fact that any reduction is desired, and arguably is needed. Cache County suffers from some of the worst air quality in the country, and changes must be made.

**Using VMT as opposed to VHT (Vehicle Hours Traveled)**

VHT certainly contributes to NO$_x$ emissions; this can be seen in the desire to reduce emissions through synchronized signal timing, which reduces VHT but leaves VMT unchanged. However, VMT, combined with the emissions/mile rate, is the generally accepted parameter used to obtain total emissions values. However, VHT is not ignored; MOBILE6.2 does incorporate the value in determining the emissions rate per mile. As would be expected, greater VMT to VHT values (this ratio is a measure of average speed in the transportation network) yield lower emissions rates; on a per mile basis, vehicles creeping along at 5 mi/h will emit more than those cruising at 35 mi/h.

**3.4 VMT to NO$_x$ Conversion**

To convert VMT to NO$_x$ is a linear conversion using the emission rates found in Table 13. The VMT (miles/day) found in the CMPO CUBE model will be multiplied by the NO$_x$ emissions rate (grams/mile) calculated by the CMPO in MOBILE6.2. This leaves the number in grams per day and then that number is divided by 453.5 (grams/pound) which converts it to pounds per day. Then the pounds per day is divided by 2,000 (pounds/ton), which leaves the number in tons per day of NO$_x$ (CMPO, 2011). This equation is shown below:
VMT (miles/day) * NO\textsubscript{x} Emission Rate (grams/miles)

453.5 (grams/lbs) * 2000 (lbs/tons)
CHAPTER 4
MODELING AND FINDINGS

4.1 Introduction

Four different scenarios were modeled in CUBE Voyager using the methodology detailed in Chapter 3. Each scenario included the years of 2010, 2020, 2030, and 2035 with their corresponding demographic and socioeconomic data. In all scenarios there were two different sets of data; one with the 2010 network used for all years denoted as a “No Build” network and the other data set will use the new networks with each phase of highway capacity projects completed (see section 3.3.1) denoted as “With Phases.” Scenario 1 is a do nothing scenario just to show the VMT and NO\textsubscript{x} emissions that would be present if nothing was done to lower the pollution. Scenario 1 was used as a comparison for all the other scenarios. Scenario 2 reduces the external (IX, XI, and XX) trips for both Long and Short vehicle trips by 20%. Scenario 3 reduces Long vehicle external trips by 50% and Short vehicle external trips by 20%. Scenario 4 reduces the Long vehicle external trips by 100% and the Short vehicle external trips by 20%. Then a summary of all the scenarios will be discussed. The VMT shown for all scenarios are for the whole county to show the effect the toll on the external trips has on the whole county.

All scenarios deal with a reduction of trips and predicting the reduction in travel as a result of cordon pricing is exceedingly difficult. Surveys and detailed economic studies help, but often the data can only be accurately obtained empirically, once the system is already in place. Numerous factors, including demographics, availability of alternative transit, and cultural/political tendencies, all play a role in determining the
population’s price-responsiveness. These scenarios will show the reductions that have to be made in order to reduce the PM$_{2.5}$ below the standard. The percentage of decreased NO$_x$ was calculated for each of the four years for each scenario. In each of the four scenarios all the vehicles leaving, entering, or passing through the cordon area will be subject to the toll. The proposed toll area is shown in Figure 14 with the network taken from the CMPO model.
This area was chosen for the proposed toll area because it covers all the major roads entering and leaving the urbanized areas of the county. One of the biggest setbacks in implementing a toll is public acceptance. The decision to toll only the external areas
should help the toll be more accepted by the public in Cache County. Individuals coming from outside the county would have to pay the fee and also people passing through. The only residents of the area that would be subject to the toll would be the individuals that work outside the county or leave for external trips. Another policy that could make the fee more appealing to County residents would be a discount for residents like the one implemented in Milan. Residents of Milan are given a 50% discount for the first 50 trips in a year to make the toll more acceptable.

Setting the cordon area just around Logan, which has more attraction zones than any other city in Cache County, was considered. Because Logan has a university and other major companies, it attracts the most trips. Also, setting the cordon area just around the university and around the other major attractions in the county was considered. Both of these different considerations were eventually discarded because they would be hard to pass politically because it would affect the majority of the public in the county. Both considerations would have been harder to model because of all of the access points to these areas.

4.2 Do Nothing Scenario

This scenario assumes that nothing is done to reduce the pollution in the future and is denoted by “Scenario 1”. Both data sets are included in the results from the “No Build” data, with the 2010 network, and the “With Phases” data, which include all the network improvements over the years. The results for this scenario are shown in Table 14 using the data directly from the CMPO demand model and includes all VMT for the whole county.
Table 14: Do Nothing Scenario Results

<table>
<thead>
<tr>
<th>Year</th>
<th>Emission Rate (grams/mile)</th>
<th>VMT</th>
<th>NOx (tons/day)</th>
<th>VMT</th>
<th>NOx (tons/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No Build</td>
<td>With Phases</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2010</td>
<td>1.7</td>
<td>3.6</td>
<td>1862717</td>
<td>1862717</td>
<td>3.6</td>
</tr>
<tr>
<td>2020</td>
<td>0.8</td>
<td>2.1</td>
<td>2261260</td>
<td>2465894</td>
<td>2.2</td>
</tr>
<tr>
<td>2030</td>
<td>0.6</td>
<td>1.8</td>
<td>2681922</td>
<td>3122640</td>
<td>2.0</td>
</tr>
<tr>
<td>2035</td>
<td>0.6</td>
<td>1.9</td>
<td>2912697</td>
<td>3484144</td>
<td>2.2</td>
</tr>
</tbody>
</table>

Table 14 shows that with the increase capacity on the network, due to the phases, the VMT increases, as well as the pollution. Even though the pollution increases and Cache County is a non-attainment area, the CMPO is able to continue to expand the network if it does not exceed the emission of 2008. The emissions in 2008 was 5.21 tons/day of NO\textsubscript{x} (CMPO, 2011). Because the emissions in tons per day is less than 5.21 in the years of 2010, 2020, 2030, and 2035 more capacity can be built. However, as can be seen in the year 2035 the NO\textsubscript{x} amount increases even though the emissions rate decreases. The amount of NO\textsubscript{x} shown in Table 14 will be the bases for comparison in the following scenarios to calculate the percent of decrease in pollution from the cordon area toll.

4.3 Trip Reduction of 20% for Long and Short Vehicles due to Toll Scenario

From the literature review it was found that a decrease around 20% of trips entering and exiting the cordon area is a reasonable number. From the Milan example
there was a decrease of around 20% for both the smaller and larger vehicles. The London example shows that the percentage of a 17% decrease in vehicles per kilometer in the cordon area. This percentage decrease in vehicles per kilometer would amount to a number much greater than a 20% decrease in external vehicles trips. For example, the VMT reduction in this scenario for Cache County in 2010 is only 6% with a 20% reduction of the external trips. In Singapore when they first implemented a pricing scheme the traffic entering the restricted area decreased by 45%. This scenario takes a modest approach with a 20% reduction of trips for all vehicles entering, exiting, and passing through the cordon area.

The script was changed in the CMPO travel demand model under the Final Highway Assignment section. The script file that converts production and attraction person trips to origin and destination vehicle trips was changed. The area highlighted in the black box in Figure 15 shows the exact location in the program where a change in the script was made.
In the script file there is a section that calculates the short versus long trip matrices. This section separates the short and long vehicles into subsections of AM peak, Mid-day, PM peak, and Evening. Within each subsection there are the six trip purposes of HBW, HBC, HBO, NHB, EXT, and COMM. Each of the EXT parts of each subsection was multiplied by 0.8 to simulate a 20% decrease. The section of the script file taken from the CMPO model is in Appendix A, the parts that were changed are underlined. After the script was changed each year was run with the two different networks of “No Build” and “With Phases”. The results for a 20% reduction of trips entering, leaving, and passing through the cordon area are shown in Table 15.
shows the decrease in VMT for the entire county in graphical form due to the 20% reduction.

Table 15: 20% Trip Reduction for Long & Short Vehicles

<table>
<thead>
<tr>
<th>Year</th>
<th>No Build</th>
<th>With Phases</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Do Nothing Emission (tons/day)</td>
<td>VMT</td>
</tr>
<tr>
<td>2010</td>
<td>3.6</td>
<td>1747415</td>
</tr>
<tr>
<td>2020</td>
<td>2.1</td>
<td>2144667</td>
</tr>
<tr>
<td>2030</td>
<td>1.8</td>
<td>2563514</td>
</tr>
<tr>
<td>2035</td>
<td>1.9</td>
<td>2794567</td>
</tr>
</tbody>
</table>

Figure 16: Different VMT Levels for Scenarios 1 and 2
As shown in Table 15 the NO\textsubscript{x} production decreases from 4 to 6 percent with the “No Build” and over 6 percent in the “With Phases” scenario. This is a good start because any reduction is an acceptable result but does not meet the 12.5% reduction that was discussed in section 3.3.2 as the provisional goal to be able to reduce the PM\textsubscript{2.5} levels below 35 \(\mu g/m^3\) into attainment. The next scenarios will try to meet this provisional goal. The VMT reduction shown in Figure 16 shows that with a 20% decrease in external trips the highest percentage of VMT decrease was 6%.

4.4 20% Short & 50% Long Vehicle External Trip Reduction due to Toll Scenario

This section models the effects on NO\textsubscript{x} emissions from a cordon pricing plan, evaluating both 20% and 50% reductions in external trips for Short and Long vehicles, respectively. One of the largest advantages of cordon pricing is that the fee charged can be varied to obtain the desired reduction in demand. For example, in London, the original £5 (US $8) proved insufficient to reduce the number entering vehicles to the desired extent, so it was soon raised to £8 (US $13) (Larson and Sasanuma, 2010), and is now £10 (US $16). Also, the pricing scheme in Milan varies the price based on emissions rating. The worse the emission rate, the higher the toll. The rate for the Long vehicles can be set at a higher price because they are assumed to emit more pollution, causing a modal shift to a smaller vehicle or to the bus. This scenario was run to try and meet the goal of a 12.5% reduction by decreasing the vehicles that emit more pollution. The 50% of Long vehicles reduced is assumed to be the semi-tractor trailers that do not need to come into or leave the county and mainly larger vehicles like SUVs or pickup trucks. However, because Cache County relies heavily on semi-tractor trailers it is not expected that a large number of these vehicles would be included in the reduction.
This scenario was modeled like the scenario in section 4.3 except the EXT for Long vehicles was multiplied by 0.5 to signify the 50% trip reduction and the Short vehicles were multiplied by 0.8 for the 20% trip reduction in the script file. The section of the script file taken from the CMPO model is shown in Appendix B, parts that were changed are underlined. After the script was changed each year was run with the two different networks of “No Build” and “With Phases”. The results for a 20% reduction of Short vehicle and 50% reduction of Long vehicle trips entering, leaving, and passing through the cordon area are shown in Table 16. Figure 17 shows the decrease in VMT for the entire county in graphical form due to the reduction in external trips in this scenario.

Table 16: 20% Short & 50% Long Vehicle Trip Reduction

<table>
<thead>
<tr>
<th>Year</th>
<th>No Build</th>
<th>With Phases</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Do Nothing Emission (tons/day)</td>
<td>VMT (tons/day)</td>
</tr>
<tr>
<td>2010</td>
<td>3.6</td>
<td>1575486</td>
</tr>
<tr>
<td>2020</td>
<td>2.1</td>
<td>1973434</td>
</tr>
<tr>
<td>2030</td>
<td>1.8</td>
<td>2389366</td>
</tr>
<tr>
<td>2035</td>
<td>1.9</td>
<td>2616116</td>
</tr>
</tbody>
</table>
By reducing the Long vehicles external trips by 50% and the Short vehicles by 20%, the change in NO\textsubscript{x} was between 10 and 15.4 percent for the no build data. The years of 2010 and 2020 meet the provisional goal of 12.5% reduction, but 2030 and 2035 fall just short with the “No Build” data. For the “With Phases” data the decrease in change was between 15.4 and 15.8 percent, which was above the provisional goal. The VMT reduction shown in Figure 17 shows that with the Scenario 3 decrease in external trips, the highest percentage of VMT decrease was 15.8%.

4.5 20% Short & 100% Long Vehicle External Trip Reduction due to Toll Scenario

This section models the effects on NO\textsubscript{x} emissions from a cordon pricing plan, evaluating both 20% and 100% reductions in external trips for Short and Long vehicles, respectively. This section models what would happen if the toll rate was so high that Long vehicles would not want to enter or exit the area. This model assumes that all
owners of Long vehicles will have a modal switch to a Short vehicle or bus. This scenario is not practical and could never be implemented because Cache County relies heavily on imports and export of by tractor-trailers. This scenario was run to simply observe the impact that longer vehicles entering, leaving, and passing through the county have on the amount of pollution produced.

This scenario was modeled like the scenario in section 4.3 and 4.4 except the EXT for Long vehicles was multiplied by 0 to signify the 100% trip reduction and the Short vehicles were multiplied by 0.8 for the 20% trip reduction in the script file. The section of the script file taken from the CMPO model is shown below in Appendix C the parts that were changed are underlined. After the script was changed each year was run with the two different networks of “No Build” and “With Phases”. The results for a 20% reduction of Short vehicle and 100% reduction of Long vehicle trips entering, leaving, and passing through the cordon area are shown in Table 17. Figure 18 shows the decrease in VMT for the entire county in graphical form due to the reduction in external trips in this scenario.

Table 17: 20% Short & 100% Long Vehicle Trip Reduction

<table>
<thead>
<tr>
<th>Year</th>
<th>Do Nothing Emission</th>
<th>VMT</th>
<th>NOx</th>
<th>% Change</th>
<th>Do Nothing Emission</th>
<th>VMT</th>
<th>NOx</th>
<th>% Change</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(tons/day)</td>
<td></td>
<td>(tons/day)</td>
<td></td>
<td>(tons/day)</td>
<td></td>
<td>(tons/day)</td>
<td></td>
</tr>
<tr>
<td>2010</td>
<td>3.6</td>
<td>1289118</td>
<td>2.5</td>
<td>-30.8</td>
<td>3.6</td>
<td>1289118</td>
<td>2.5</td>
<td>-30.8</td>
</tr>
<tr>
<td>2020</td>
<td>2.1</td>
<td>1686538</td>
<td>1.5</td>
<td>-25.4</td>
<td>2.2</td>
<td>1697360</td>
<td>1.5</td>
<td>-31.2</td>
</tr>
<tr>
<td>2030</td>
<td>1.8</td>
<td>2100115</td>
<td>1.4</td>
<td>-21.7</td>
<td>2.0</td>
<td>2150205</td>
<td>1.4</td>
<td>-31.1</td>
</tr>
<tr>
<td>2035</td>
<td>1.9</td>
<td>2325839</td>
<td>1.5</td>
<td>-20.1</td>
<td>2.2</td>
<td>2387876</td>
<td>1.5</td>
<td>-31.5</td>
</tr>
</tbody>
</table>
By reducing the Long vehicles completely the percent in change of NO\textsubscript{x} almost doubles from the 50% external trip reduction of Long vehicles. With the “No Build” network the NO\textsubscript{x} was reduced between 20.1 and 30.8 percent which decreases all the years below the provisional goal of 12.5%. The “With Phases” network decreased the NO\textsubscript{x} between 30.8 and 31.5 percent which is more than double the provisional goal. Although this scenario gives the best results it would be improbable to decrease all the Long vehicles because of the dependence Cache County has on semi-tractor trailer for the all the imports and exports of goods. The highest percentage decrease in VMT shown in Figure 18 is a 31.5% decrease in the year 2035 for the “With Phases” network. This is more than needed and an improbable solution but shows that the external trips of Long vehicles have a huge impact on the county.
4.6 Summary of Scenarios

There were four scenarios run in the modeling and the change in NO\textsubscript{x} is summarized in Table 18 for the “No Build” network. Table 19 summarizes the change in NO\textsubscript{x} for the “With Phases” network and all values are in tons per day for both tables. In Table 18 and 19, Scenario 1 is the do nothing scenario, Scenario 2 is the 20% external trip reduction for both Long and Short vehicles scenario, Scenario 3 is the 50% and 20% external trip reduction for both Long and Short vehicles respectively, and Scenario 4 is the 100% and 20% external trip reduction for both Long and Short vehicles, respectively. The NO\textsubscript{x} levels for each scenario using “No Build” network are shown graphically in Figure 19.

Table 18: Summary of Change in NO\textsubscript{x} for No Build Network

<table>
<thead>
<tr>
<th>Year</th>
<th>Scenario 1</th>
<th>Scenario 2</th>
<th>Scenario 3</th>
<th>Scenario 4</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>NO\textsubscript{x}</td>
<td>NO\textsubscript{x}</td>
<td>% Change</td>
<td>NO\textsubscript{x}</td>
</tr>
<tr>
<td>2010</td>
<td>3.6</td>
<td>3.4</td>
<td>-6.2</td>
<td>3.0</td>
</tr>
<tr>
<td>2020</td>
<td>2.1</td>
<td>2.0</td>
<td>-5.2</td>
<td>1.8</td>
</tr>
<tr>
<td>2030</td>
<td>1.8</td>
<td>1.7</td>
<td>-4.4</td>
<td>1.6</td>
</tr>
<tr>
<td>2035</td>
<td>1.9</td>
<td>1.78</td>
<td>-4.1</td>
<td>1.7</td>
</tr>
</tbody>
</table>
With the provisional goal set at 12.5% decrease of NO\textsubscript{x} production needed to reduce the PM\textsubscript{2.5} from 40 $\mu$g/m\textsuperscript{3} to 35 $\mu$g/m\textsuperscript{3}. With the “No Build” network scenario 3 decreases the NO\textsubscript{x} enough to reduce the PM\textsubscript{2.5} under the 12.5% goal until 2030 and 2035. Scenario 4 also met the goal, in terms of percentage decrease, but because the scenario is improbable it will not be considered as a viable option. The NO\textsubscript{x} levels for each scenario using “With Phases” network are shown graphically in Figure 20.

<table>
<thead>
<tr>
<th>Year</th>
<th>Scenario 1</th>
<th>Scenario 2</th>
<th>Scenario 3</th>
<th>Scenario 4</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>NO\textsubscript{x}</td>
<td>NO\textsubscript{x}</td>
<td>% Change</td>
<td>NO\textsubscript{x}</td>
</tr>
<tr>
<td>2010</td>
<td>3.6</td>
<td>3.4</td>
<td>-6.2</td>
<td>3.0</td>
</tr>
<tr>
<td>2020</td>
<td>2.2</td>
<td>2.1</td>
<td>-6.3</td>
<td>1.9</td>
</tr>
<tr>
<td>2030</td>
<td>2.0</td>
<td>1.9</td>
<td>-6.3</td>
<td>1.7</td>
</tr>
<tr>
<td>2035</td>
<td>2.2</td>
<td>2.1</td>
<td>-6.4</td>
<td>1.9</td>
</tr>
</tbody>
</table>
For the “With Phases” network the NO\textsubscript{x} levels in scenarios 3 and 4 are reduced enough to decrease the PM\textsubscript{2.5} production under the 12.5\% goal. The “With Phases” network is the more important of the two networks because the Cache MPO already has funding for the capacity building projects and are already in the process of completing phase 1. Even though the “With Phases” network has a higher VMT and NO\textsubscript{x} production than the “No Build” network, it has a higher decrease in percentage. This is because the NO\textsubscript{x} production in tons per day for “With Phases” network in Scenario 1 (Do Nothing Scenario) is higher than the NO\textsubscript{x} in the “No Build” network. The VMT change for all scenarios is shown in Figures 21 and 22 for both “Do Nothing” and “With Phases” networks, respectively. Both graphs show the affect the decrease in external trips has on the total VMT for the whole county.

![Figure 20: NO\textsubscript{x} Levels for all Scenario using With Phases Network](image-url)
Figure 21: VMT Change for All Scenarios for No Build Network

Figure 22: VMT Change for All Scenarios for With Phases Network
5.1 Conclusions

It is apparent that there is a pollution problem in Cache County with the high PM$_{2.5}$ levels during the winter months of November to February because of the geographical nature of the area that is prone to inversions. With all of the adverse affects that PM$_{2.5}$ has on the health of the surrounding communities action needs to be taken to reduce it. The research in this project evaluated an estimated reduction of external vehicle trips needed to reduce the PM$_{2.5}$ levels to meet the EPA standards using a cordon area pricing scheme. The 24-hour 98$^{th}$ percentile is the biggest problem Cache County faces with the average of the 3-year averages from the years 2008, 2009, and 2010 being around 40 µg/m$^3$. The EPA standard for the 24-hour 98$^{th}$ percentile is 35 µg/m$^3$, which is a 12.5% decrease from the 40 µg/m$^3$, so a provisional goal was set at a 12.5% reduction. With the proposed cordon area pricing scheme around Cache County there was four scenarios ran to observe which would meet the provisional goal in a realistic manner.

The first scenario was a “Do Nothing” scenario that was used to calculate the reduction of PM$_{2.5}$ for all other scenarios. The scenario with the best results was scenario 4, which decreased the external Short vehicles by 20% and the Long vehicles by 100%. This scenario had the most reduction in NO$_x$ and PM$_{2.5}$ but it is improbable that a 100% reduction from Long vehicles would happen because of the heavy dependence of tractor-trailers to import and export goods. Scenario 2 does decrease the PM$_{2.5}$ production and is the scenario that matches the decrease in trips in other countries. However, it does not
meet the provisional goal of a 12.5% decrease to reduce the PM$_{2.5}$ to the EPA standard of 35 $\mu$g/m$^3$. Scenario 3 gave the most promising results using the “With Phases” network. Because Cache County is in the process of increasing the capacity of the roadways, the “With Phases” was the more important data set. With the decrease of external Short vehicles by 20% and Long vehicle by 50%, scenario 3 resulted in a 15.4% to 15.8% reduction in PM$_{2.5}$. This scenario met the goal and is a reasonable result that can be obtained by a differentiation-based charge based on emission standards.

5.2 Future Recommendations

If Cache County decides to implement a cordon area pricing scheme the public needs to be informed first of the pollution problem and the effects of PM$_{2.5}$ before the pricing scheme can be addressed. The public needs to know where the toll revenue is being spent and that they will benefit even more from it. The toll revenue should be spent on public transport because of the increase in ridership. The revenue can also be used to build park-and-rides outside the pricing area to allow commuters the opportunity to still enter Cache County without paying the toll.

The most efficient way to operate the tolling system in Cache County would be to implement a system similar system to London, Stockholm, and Milan. They all use automated number plate recognition (ANPR) with cameras set up at entry points. Cache County could do the same to reduce the external vehicle trips. With ANPR the cordon area can be run more efficiently. To further this study, surveys and detailed economic studies are needed for the price sensitivity of the public to calculate the toll price needed to decrease the external trip and ultimately the PM$_{2.5}$. Also, different sizes of cordon areas within the county can be addressed to find the optimal area size.
REFERENCES


Grant, Christopher Daniel. (1998). “Representative vehicle operating mode frequencies: measurement and prediction of vehicle specific freeway modal activity.” Georgia Institute of Technology.


APPENDICES

Appendix A: Script from CUBE model for Scenario 2 with changes underlined

; calc directional, short vs long trip matrices
JLOOP
; long trips
if (mi.2.distance[j] >= @LongTripBreakPt@)
  ; AM Peak LONG TRIPS
  mw[221] = mw[51] * _AM_HBW_PA + mw[61] * _AM_HBW_AP ; HBW (% out of peak)
  mw[222] = mw[52] * @AM_HBC_PA@ + mw[62] * @AM_HBC_AP@ ; HBC (% out of daily)
  mw[223] = mw[53] * _AM_HBO_PA + mw[63] * _AM_HBO_AP ; HBO (% out of peak)
  mw[224] = mw[54] * @AM_NHB_PA + mw[64] * @AM_NHB_AP ; NHB (% out of peak)
  mw[225] = (mw[205] * @AM_EXT_PA@ + mw[215] * @AM_EXT_AP@) * 0.8 ; EXT (% out of daily)
  mw[227] = mw[207] * @AM_COM_PA@ + mw[217] * @AM_COM_AP@ ; COMM (% out of daily)
; Mid-day LONG TRIPS
  mw[231] = mw[71] * _MD_HBW_PA + mw[81] * _MD_HBW_AP ; HBW (% out of peak)
  mw[232] = mw[72] * @MD_HBC_PA@ + mw[82] * @MD_HBC_AP@ ; HBC (% out of daily)
  mw[233] = mw[73] * _MD_HBO_PA + mw[83] * _MD_HBO_AP ; HBO (% out of peak)
  mw[234] = mw[74] * _MD_NHB_PA + mw[84] * _MD_NHB_AP ; NHB (% out of peak)
  mw[235] = (mw[205] * @MD_EXT_PA@ + mw[215] * @MD_EXT_AP@) * 0.8 ; EXT (% out of daily)
  mw[237] = mw[207] * @MD_COM_PA@ + mw[217] * @MD_COM_AP@ ; COMM (% out of daily)
; PM peak LONG TRIPS
  mw[241] = mw[51] * _PM_HBW_PA + mw[61] * _PM_HBW_AP ; HBW
  mw[242] = mw[52] * @PM_HBC_PA@ + mw[62] * @PM_HBC_AP@ ; HBC
  mw[243] = mw[53] * _PM_HBO_PA + mw[63] * _PM_HBO_AP ; HBO
  mw[244] = mw[54] * _PM_NHB_PA + mw[64] * _PM_NHB_AP ; NHB
  mw[245] = (mw[205] * @PM_EXT_PA@ + mw[215] * @PM_EXT_AP@) * 0.8 ; EXT
  mw[247] = mw[207] * @PM_COM_PA@ + mw[217] * @PM_COM_AP@ ; COMM
; Evening LONG TRIPS
  mw[251] = mw[71] * _EV_HBW_PA + mw[81] * _EV_HBW_AP ; HBW
  mw[252] = mw[72] * @EV_HBC_PA@ + mw[82] * @EV_HBC_AP@ ; HBC
  mw[253] = mw[73] * _EV_HBO_PA + mw[83] * _EV_HBO_AP ; HBO
  mw[254] = mw[74] * _EV_NHB_PA + mw[84] * _EV_NHB_AP ; NHB
  mw[255] = (mw[205] * @EV_EXT_PA@ + mw[215] * @EV_EXT_AP@) * 0.8 ; EXT
  mw[257] = mw[207] * @EV_COM_PA@ + mw[217] * @EV_COM_AP@ ; COMM
; short trip
else
  ; AM Peak SHORT TRIPS
  mw[261] = mw[51] * _AM_HBW_PA + mw[61] * _AM_HBW_AP ; HBW (% out of peak)
  mw[262] = mw[52] * @AM_HBC_PA@ + mw[62] * @AM_HBC_AP@ ; HBC (% out of daily)
  mw[263] = mw[53] * _AM_HBO_PA + mw[63] * _AM_HBO_AP ; HBO (% out of peak)
  mw[264] = mw[54] * _AM_NHB_PA + mw[64] * _AM_NHB_AP ; NHB (% out of peak)
  mw[265] = (mw[205] * @AM_EXT_PA@ + mw[215] * @AM_EXT_AP@) * 0.8 ; EXT (% out of daily)
  mw[267] = mw[207] * @AM_COM_PA@ + mw[217] * @AM_COM_AP@ ; COMM (% out of daily)
; Mid-day SHORT TRIPS
  mw[271] = mw[71] * _MD_HBW_PA + mw[81] * _MD_HBW_AP ; HBW (% out of peak)
  mw[272] = mw[72] * @MD_HBC_PA@ + mw[82] * @MD_HBC_AP@ ; HBC (% out of daily)
  mw[273] = mw[73] * _MD_HBO_PA + mw[83] * _MD_HBO_AP ; HBO (% out of peak)
  mw[274] = mw[74] * _MD_NHB_PA + mw[84] * _MD_NHB_AP ; NHB (% out of peak)
  mw[275] = (mw[205] * @MD_EXT_PA@ + mw[215] * @MD_EXT_AP@) * 0.8 ; EXT (% out of daily)
  mw[277] = mw[207] * @MD_COM_PA@ + mw[217] * @MD_COM_AP@ ; COMM (% out of daily)
; PM peak SHORT TRIPS
mw[281] = mw[51] * _PM_HBW_PA  + mw[61] * _PM_HBW_AP  ;HBW (% out of peak)
mw[282] = mw[52] * @PM_HBC_PA@  + mw[62] * @PM_HBC_AP@  ;HBC (% out of daily)
mw[283] = mw[53] * _PM_HBO_PA  + mw[63] * _PM_HBO_AP  ;HBO (% out of peak)
mw[284] = mw[54] * _PM_NHB_PA  + mw[64] * _PM_NHB_AP  ;NHB (% out of peak)

mw[285] = (mw[205]* @PM_EXT_PA@ + mw[215]* @PM_EXT_AP@) * 0.8  ;EXT (% out of daily)

mw[287] = (mw[207]* @PM_COM_PA@ + mw[217]* @PM_COM_AP@) ;COMM (% out of daily)

ENDJLOOP

Appendix B: Script from CUBE model for Scenario 3 with changes underlined

;calc directional, short vs long trip matrices
JLOOP
;long trips
if (mi.2.distance[j] >= @LongTripBreakPt@)
  ;AM Peak LONG TRIPS
  mw[221] = mw[51] * _AM_HBW_PA  + mw[61] * _AM_HBW_AP  ;HBW (% out of peak)
  mw[222] = mw[52] * @AM_HBC_PA@  + mw[62] * @AM_HBC_AP@  ;HBC (% out of daily)
  mw[223] = mw[53] * _AM_HBO_PA  + mw[63] * _AM_HBO_AP  ;HBO (% out of peak)
  mw[224] = mw[54] * _AM_NHB_PA  + mw[64] * _AM_NHB_AP  ;NHB (% out of peak)
  mw[225] = (mw[205]* @AM_EXT_PA@ + mw[215]* @AM_EXT_AP@) * 0.5  ;EXT (% out of daily)

  mw[227] = mw[207]* @AM_COM_PA@ + mw[217]* @AM_COM_AP@  ;COMM (% out of daily)
  ;Mid-day LONG TRIPS
  mw[231] = mw[71] * _MD_HBW_PA  + mw[81] * _MD_HBW_AP  ;HBW (% out of peak)
  mw[232] = mw[72] * @MD_HBC_PA@  + mw[82] * @MD_HBC_AP@  ;HBC (% out of daily)
  mw[233] = mw[73] * _MD_HBO_PA  + mw[83] * _MD_HBO_AP  ;HBO (% out of peak)
  mw[234] = mw[74] * _MD_NHB_PA  + mw[84] * _MD_NHB_AP  ;NHB (% out of peak)
  mw[235] = (mw[205]* @MD_EXT_PA@ + mw[215]* @MD_EXT_AP@) * 0.5  ;EXT (% out of daily)

  mw[237] = mw[207]* @MD_COM_PA@ + mw[217]* @MD_COM_AP@  ;COMM (% out of daily)
  ;PM peak LONG TRIPS
  mw[241] = mw[51] * _PM_HBW_PA  + mw[61] * _PM_HBW_AP  ;HBW
  mw[242] = mw[52] * @PM_HBC_PA@  + mw[62] * @PM_HBC_AP@  ;HBC
  mw[243] = mw[53] * _PM_HBO_PA  + mw[63] * _PM_HBO_AP  ;HBO
  mw[244] = mw[54] * _PM_NHB_PA  + mw[64] * _PM_NHB_AP  ;NHB
  mw[245] = (mw[205]* @PM_EXT_PA@ + mw[215]* @PM_EXT_AP@) * 0.5  ;EXT

  mw[247] = mw[207]* @PM_COM_PA@ + mw[217]* @PM_COM_AP@  ;COMM
  ;Evening LONG TRIPS
  mw[251] = mw[71] * _EV_HBW_PA  + mw[81] * _EV_HBW_AP  ;HBW
  mw[252] = mw[72] * @EV_HBC_PA@  + mw[82] * @EV_HBC_AP@  ;HBC
  mw[253] = mw[73] * _EV_HBO_PA  + mw[83] * _EV_HBO_AP  ;HBO
  mw[254] = mw[74] * _EV_NHB_PA  + mw[84] * _EV_NHB_AP  ;NHB
  mw[255] = (mw[205]* @EV_EXT_PA@ + mw[215]* @EV_EXT_AP@) * 0.5  ;EXT

  mw[257] = mw[207]* @EV_COM_PA@ + mw[217]* @EV_COM_AP@  ;COMM

;short trips
else
  ;AM Peak SHORT TRIPS
  mw[261] = mw[51] * _AM_HBW_PA  + mw[61] * _AM_HBW_AP  ;HBW (% out of peak)
mw[262] = mw[52] * @AM_HBC_PA@ + mw[62] * @AM_HBC_AP@ ;HBC (% out of daily)
mw[263] = mw[53] * _AM_HBO_PA  + mw[63] * _AM_HBO_AP ;HBO (% out of peak)
mw[264] = mw[54] * _AM_NHB_PA  + mw[64] * _AM_NHB_AP ;NHB (% out of peak)
mw[265] = (mw[205]* @AM_EXT_PA@ + mw[215]* @AM_EXT_AP@) * 0.8 ;EXT (% out of daily)
mw[267] = mw[207]* @AM_COM_PA@ + mw[217]* @AM_COM_AP@ ;COMM (% out of daily)

;Mid-day SHORT TRIPS
mw[271] = mw[71] * _MD_HBW_PA  + mw[81] * _MD_HBW_AP ;HBW (% out of peak)
mw[272] = mw[72] * @MD_HBC_PA@ + mw[82] * @MD_HBC_AP@ ;HBC (% out of daily)
mw[273] = mw[73] * _MD_HBO_PA  + mw[83] * _MD_HBO_AP ;HBO (% out of peak)
mw[274] = mw[74] * _MD_NHB_PA  + mw[84] * _MD_NHB_AP ;NHB (% out of peak)
mw[275] = (mw[205]* @MD_EXT_PA@ + mw[215]* @MD_EXT_AP@) * 0.8 ;EXT (% out of daily)
mw[277] = mw[207]* @MD_COM_PA@ + mw[217]* @MD_COM_AP@ ;COMM (% out of daily)

;PM peak SHORT TRIPS
mw[281] = mw[51] * _PM_HBW_PA  + mw[61] * _PM_HBW_AP ;HBW (% out of peak)
mw[282] = mw[52] * @PM_HBC_PA@ + mw[62] * @PM_HBC_AP@ ;HBC (% out of daily)
mw[283] = mw[53] * _PM_HBO_PA  + mw[63] * _PM_HBO_AP ;HBO (% out of peak)
mw[284] = mw[54] * _PM_NHB_PA  + mw[64] * _PM_NHB_AP ;NHB (% out of peak)
mw[285] = (mw[205]* @PM_EXT_PA@ + mw[215]* @PM_EXT_AP@) * 0.8 ;EXT (% out of daily)
mw[287] = mw[207]* @PM_COM_PA@ + mw[217]* @PM_COM_AP@ ;COMM (% out of daily)

;Evening SHORT TRIPS
mw[291] = mw[71] * _EV_HBW_PA  + mw[81] * _EV_HBW_AP ;HBW (% out of peak)
mw[292] = mw[72] * @EV_HBC_PA@ + mw[82] * @EV_HBC_AP@ ;HBC (% out of daily)
mw[293] = mw[73] * _EV_HBO_PA  + mw[83] * _EV_HBO_AP ;HBO (% out of peak)
mw[294] = mw[74] * _EV_NHB_PA  + mw[84] * _EV_NHB_AP ;NHB (% out of peak)
mw[295] = (mw[205]* @EV_EXT_PA@ + mw[215]* @EV_EXT_AP@) * 0.8 ;EXT (% out of daily)
mw[297] = mw[207]* @EV_COM_PA@ + mw[217]* @EV_COM_AP@ ;COMM (% out of daily)
endif
ENDJLOOP

Appendix C: Script from CUBE model for Scenario 4 with changes underlined

;calc directional, short vs long trip matrices
JLOOP ;long trips
if (mi.2.distance[j] >= @LongTripBreakPt@)
;AM Peak LONG TRIPS
mw[221] = mw[51] * _AM_HBW_PA  + mw[61] * _AM_HBW_AP ;HBW (% out of peak)
mw[222] = mw[52] * @AM_HBC_PA@ + mw[62] * @AM_HBC_AP@ ;HBC (% out of daily)
mw[223] = mw[53] * _AM_HBO_PA  + mw[63] * _AM_HBO_AP ;HBO (% out of peak)
mw[224] = mw[54] * _AM_NHB_PA  + mw[64] * _AM_NHB_AP ;NHB (% out of peak)
mw[225] = (mw[205]* @AM_EXT_PA@ + mw[215]* @AM_EXT_AP@) * 0 ;EXT (% out of daily)
mw[227] = mw[207]* @AM_COM_PA@ + mw[217]* @AM_COM_AP@ ;COMM (% out of daily)

;Mid-day LONG TRIPS
mw[231] = mw[71] * _MD_HBW_PA  + mw[81] * _MD_HBW_AP ;HBW (% out of peak)
mw[232] = mw[72] * @MD_HBC_PA@ + mw[82] * @MD_HBC_AP@ ;HBC (% out of daily)
mw[233] = mw[73] * _MD_HBO_PA  + mw[83] * _MD_HBO_AP ;HBO (% out of peak)
mw[234] = mw[74] * _MD_NHB_PA  + mw[84] * _MD_NHB_AP ;NHB (% out of peak)
mw[235] = (mw[205]* @MD_EXT_PA@ + mw[215]* @MD_EXT_AP@) * 0 ;EXT (% out of daily)
mw[237] = mw[207]* @MD_COM_PA@ + mw[217]* @MD_COM_AP@ ;COMM (% out of daily)

;PM peak LONG TRIPS
mw[241] = mw[51] * _PM_HBW_PA  + mw[61] * _PM_HBW_AP ;HBW
mw[242] = mw[52] * @PM_HBC_PA@ + mw[62] * @PM_HBC_AP@ ;HBC
mw[243] = mw[53] * _PM_HBO_PA  + mw[63] * _PM_HBO_AP ;HBO
mw[244] = mw[54] * _PM_NHB_PA  + mw[64] * _PM_NHB_AP ;NHB
mw[245] = (mw[205]* @PM_EXT_PA@ + mw[215]* @PM_EXT_AP@) * 0 ;EXT
mw[247] = mw[207]* @PM_COM_PA@ + mw[217]* @PM_COM_AP@ ;COM
:Evening LONG TRIPS
mw[251] = mw[71] * _EV_HBW_PA  + mw[81] * _EV_HBW_AP ;HBW
mw[252] = mw[72] * @EV_HBC_PA@ + mw[82] * @EV_HBC_AP@ ;HBC
mw[253] = mw[73] * _EV_HBO_PA  + mw[83] * _EV_HBO_AP ;HBO
mw[254] = mw[74] * _EV_NHB_PA  + mw[84] * _EV_NHB_AP ;NHB
mw[255] = (mw[205]* @EV_EXT_PA@ + mw[215]* @EV_EXT_AP@) * 0 ;EXT
mw[257] = mw[207]* @EV_COM_PA@ + mw[217]* @EV_COM_AP@ ;COM
:short trip
else ;AM Peak SHORT TRIPS
mw[261] = mw[51] * _AM_HBW_PA  + mw[61] * _AM_HBW_AP ;HBW (% out of peak)
mw[262] = mw[52] * @AM_HBC_PA@ + mw[62] * @AM_HBC_AP@ ;HBC (% out of daily)
mw[263] = mw[53] * _AM_HBO_PA  + mw[63] * _AM_HBO_AP ;HBO (% out of peak)
mw[264] = mw[54] * _AM_NHB_PA  + mw[64] * _AM_NHB_AP ;NHB (% out of peak)
mw[265] = (mw[205]* @AM_EXT_PA@ + mw[215]* @AM_EXT_AP@) * 0.8 ;EXT (% out of daily)
mw[267] = mw[207]* @AM_COM_PA@ + mw[217]* @AM_COM_AP@ ;COMM (% out of daily)
:Mid-day SHORT TRIPS
mw[271] = mw[71] * _MD_HBW_PA  + mw[81] * _MD_HBW_AP ;HBW (% out of peak)
mw[272] = mw[72] * @MD_HBC_PA@ + mw[82] * @MD_HBC_AP@ ;HBC (% out of daily)
mw[273] = mw[73] * _MD_HBO_PA  + mw[83] * _MD_HBO_AP ;HBO (% out of peak)
mw[274] = mw[74] * _MD_NHB_PA  + mw[84] * _MD_NHB_AP ;NHB (% out of peak)
mw[275] = (mw[205]* @MD_EXT_PA@ + mw[215]* @MD_EXT_AP@) * 0.8 ;EXT (% out of daily)
mw[277] = mw[207]* @MD_COM_PA@ + mw[217]* @MD_COM_AP@ ;COMM (% out of daily)
:PM peak SHORT TRIPS
mw[281] = mw[51] * _PM_HBW_PA  + mw[61] * _PM_HBW_AP ;HBW (% out of peak)
mw[282] = mw[52] * @PM_HBC_PA@ + mw[62] * @PM_HBC_AP@ ;HBC (% out of daily)
mw[283] = mw[53] * _PM_HBO_PA  + mw[63] * _PM_HBO_AP ;HBO (% out of peak)
mw[284] = mw[54] * _PM_NHB_PA  + mw[64] * _PM_NHB_AP ;NHB (% out of peak)
mw[285] = (mw[205]* @PM_EXT_PA@ + mw[215]* @PM_EXT_AP@) * 0.8 ;EXT (% out of daily)
mw[287] = mw[207]* @PM_COM_PA@ + mw[217]* @PM_COM_AP@ ;COMM (% out of daily)
:Evening SHORT TRIPS
mw[291] = mw[71] * _EV_HBW_PA  + mw[81] * _EV_HBW_AP ;HBW (% out of peak)
mw[292] = mw[72] * @EV_HBC_PA@ + mw[82] * @EV_HBC_AP@ ;HBC (% out of daily)
mw[293] = mw[73] * _EV_HBO_PA  + mw[83] * _EV_HBO_AP ;HBO (% out of peak)
mw[294] = mw[74] * _EV_NHB_PA  + mw[84] * _EV_NHB_AP ;NHB (% out of peak)
mw[295] = (mw[205]* @EV_EXT_PA@ + mw[215]* @EV_EXT_AP@) * 0.8 ;EXT (% out of daily)
mw[297] = mw[207]* @EV_COM_PA@ + mw[217]* @EV_COM_AP@ ;COMM (% out of daily)
endif
ENDJLOOP