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Assessing the Cost-Effectiveness of Wyoming's CMAQ Unpaved Road Dust Suppression Program, Year 1

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Disclaimer

ABSTRACT

The Congestion Mitigation and Air Quality Improvement (CMAQ) program was implemented to provide funding to transportation projects that contribute to air quality improvements. Wyoming has used these funds for a number of years to apply dust suppressants to unpaved roads around the state. Many of these roads are impacted by oil and gas drilling activities. Decisions as to where these funds should be applied are based on subjective judgment. Methods for applying the suppressants to roads have also been based on engineering judgment. However, there is no system in place for determining the effectiveness of dust treatment. The objective of this study is to assess the effectiveness of the CMAQ program in Wyoming. A second objective is to provide recommendations on optimizing future use of CMAQ funds. This study utilizes field data and comprehensive statistical analysis to prove the effectiveness of various dust suppressants. This includes monitoring dust suppressant application, surfacing aggregate type, traffic, weather, roadway performance, and fugitive dust emissions to provide a comprehensive assessment of the effectiveness of the dust suppression efforts paid for with CMAQ funds. Analysis of field data is also used to provide recommendations on developing a statistical model for the most cost effective use of future CMAQ funding.

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1. INTRODUCTION

1.1 Background

For a number of years, Wyoming counties have used congestion mitigation and air quality improvement (CMAQ) funds to apply dust suppressants to their unpaved roads. These funds are intended to help reduce emissions of particulate matter less than 10 μm in diameter (PM_{10}). Particulate matter is one of the U.S. Environmental Protection Agency's six criteria pollutants affecting air quality. PM_{10} is referred to as "inhalable coarse particles," such as those found near roadways. Previously, decisions as to where and how CMAQ funds are applied have been subjectively based on engineering judgment.

Figure 1.1 Dust generated from an unpaved road

This study monitors dust suppressant application, surfacing aggregate type, traffic, weather, roadway performance, and fugitive dust emissions to provide a comprehensive assessment of the effectiveness of the dust suppression efforts paid for with CMAQ funds. Due to the performance difference between unpaved roads in drier and wetter climates, the results from this study will be most applicable to the interior western United States and to other drier climates throughout the world. The methodologies developed during this study will be applicable for assessing the effectiveness of any dust control efforts, regardless of differences in precipitation.

1.2 Objectives of Research

The objective of this study is to quantify the benefits of the use of congestion mitigation and air quality (CMAQ) funds to provide Wyoming counties with funding to apply dust suppressants to their unpaved roads. There are several benefits from the use of dust suppressants, including the environmental benefit of reduced fugitive dust emissions from unpaved roads. Maintenance costs are generally reduced on treated roads since maintenance is not needed as often and gravel is not lost as quickly, so it does not need to be replaced as often. Finally, treated roads generally provide the user with a higher quality road surface with less raveling, loose aggregate, and washboards, all of which can contribute to a loss of vehicle control.

Improvements in both road surface quality and the improved visibility that arises from reductions in dust make unpaved roads safer when they are treated. The goal of this project is to determine the value of the reductions in fugitive dust emissions which are realized by using different dust suppressants and application methods in different situations. By determining the benefits realized in different situations, the results of this study will allow for cost-effective allocation of CMAQ funds in the future. On a broader scale, this study will provide information that can result in more cost-effective use of road dust suppressants in general.

1.3 Expected Outcomes

This study will provide basic information needed to use dust suppressants and CMAQ funds as efficiently as possible. When combined with knowledge about traffic characteristics and surfacing aggregate types, the most cost-effective use of dust suppressants and CMAQ funds will be established. This will benefit both those deciding how to allocate CMAQ funds and others deciding where they will get the most value out of the money they spend on dust suppression purchases and applications.

Beyond the direct benefits of lowered fugitive dust emissions and lower maintenance costs for agencies using dust suppressants, there are also substantial user cost benefits. Lower vehicle costs will result from improved surface conditions. Finally, by reducing raveling, loose aggregate, washboards, and dust, the safety of treated unpaved roads surfaces will be improved. Though it is not a direct objective of this study, it is highly likely it will save lives by improving the overall safety of unpaved roads surfaces.

1.4 Paper Organization

Chapter 1 of this report provides an overview of the topic background, the objectives, and need for quantifying the benefits of the CMAQ program and the expected outcomes of the research conducted. Chapter 2 provides a summary of the applicable literature in the field of dust suppression. This chapter also discusses the variables associated with dust on unpaved roads and ways of quantifying dust concentrations. Chapter 3 discusses the methodologies for this research. A summary of the three phases of the study, as well as a flow chart of the report organization, are included. Chapter 4 covers Phase 1 of the study. This is a discussion of the EPAM-5000 methodologies that were developed. These include recommendations for the optimal collection time, placement during data collection, and the recommended ways of analyzing the data output from collection equipment. Chapter 5 covers Phase 2 of the study and describes a correlation study conducted as part of the research. This study attempts to correlate two different devices in determining dust concentrations on unpaved roads. These devices are the CSU Dustometer and the EPAM-5000. The chapter includes the testing equipment, data collection and analysis, and final conclusions. Chapter 6, which covers Phase 3 of the study, explains the data collection process associated with determining CMAQ effectiveness. This includes the dust collection equipment used, the soil samples collected, and the traffic counts conducted on the roads. Following this is a discussion on the analyses of the collected data and a summary of the results. These include a statistical analysis of variables contributing to dust pollution, determination of dust suppressant effectiveness, and costs associated with dust suppression efforts. Chapter 7 discusses the conclusions and recommendations obtained from the study. This chapter also includes recommendation for future data collection, software and analysis use, and how counties can apply the information to increase the effectiveness of using CMAQ funds for dust suppression efforts.

2. LITERATURE REVIEW

2.1 Introduction

Dust suppressants are beneficial in a number of ways. Their primary use is to reduce airborne particulate matter pollution from unpaved roads. Dust suppressants also help seal unpaved roads, thereby reducing maintenance costs. Treated roads are generally found to be of higher quality, with fewer potholes, raveling, and washboards. Reducing dust in the air also improves visibility. These factors benefit road users by reducing vehicle maintenance and providing a safer and more comfortable drive.

The effectiveness of a dust suppressant is dependent on many influences. Weather, type of suppressant, application rate, vehicle volumes, and road material are the major factors. This chapter provides a literature review of material relevant to the study. The information gathered during the literature review helps establish methods for data collection and analysis.

2.2 Dust Pollution

Approximately 39% of the United States road network is unpaved. While unpaved roads often have low traffic volumes, they are vital to the overall road network and provide a way of transporting numerous kinds of resources. These roads often contribute to dust pollution in the atmosphere, due to the loose aggregate composition of the roadway (Epps and Ehsan, 2002). According to air pollution studies, around 34% of particulate matter in the atmosphere originates from unpaved roads nationwide (Barnard, Carlson, and Stewart, 1992). The estimated volume of dust generated from unpaved roads can be up to 10 million tons per year in the United Sates (Williams et al., 2008). This makes unpaved roads the largest source of particulate air pollution in the country. According to the Environmental Protection Agency (EPA), unpaved roads produce nearly five times as much particulate matter as construction activities and wind erosion (the next two largest sources) combined (WisDOT, 1997).

The dust released into the atmosphere from these roads is generated by vehicle traffic as well as wind (Epps and Ehsan, 2002). Vehicle generated dust is caused by the force of the wheels on the road. This force causes dust to be lifted from the road surface and into forceful air currents behind the wheels. The result of these actions is fine particulate matter being released into the atmosphere (Williams et al., 2008).

2.2.1 Health Risks

The health hazards related to dust generation are recognized and regulated by the EPA. The dust particles of concern to human health are those smaller than 10 micro meters (μm) in diameter. These are referred to as PM_{10} particles and are dangerous as they can be inhaled by humans. Once inhaled, the particles are deposited in the lungs and, in some cases, can enter the bloodstream. Since these particles are inhalable and can enter the respiratory tract, they are a common cause of allergies (Edvardsson, 2009).

Particle pollution contains microscopic solids or liquid droplets that can get deep into the lungs and cause serious health problems. Numerous scientific studies have linked particle pollution exposure to a variety of health problems, including premature death in people with heart or lung disease, nonfatal heart attacks, irregular heartbeat, aggravated asthma, decreased lung function, and increased respiratory symptoms, such as irritation of the airways, coughing, or difficulty breathing (USEPA, 2013). In rare cases the inhalation of PM_{10} can even result in acute mortality (Seaton, 1995).

Studies conducted across the country with a wide range of PM_{10} composition indicate similar results on human health from the particle emissions (Seaton, 1995). This indicates that the constitution of the particles themselves is not the determining factor in health risks; rather, the adverse health effects arise from the concentration of particles in the air. This conclusion is supported by other studies that have indicated, regardless of source or particle composition, PM_{10} particles have a similar detrimental effect on respiratory health (Edvardsson, 2009).

2.2.2 Environmental and Economic Impact

Dust pollution in the air can be a health problem for nearby livestock (WisDOT, 1997). Inhalation of fine particles by livestock can cause many of the same adverse health effects found by human inhalation. Dust generated from unpaved roads can also settle on plants up to 500 feet from the road edge, slowing their growth and reducing crop yields (WisDOT, 1997). Particulate matter has been found to, "have effects on vigor, competitive viability, and reproductive fitness of individual plants… With subsequent effects impacting ecosystem structure and function, and biodiversity" (Grantz et al., 2003). The environmental impact associated with dust pollution is magnified in areas such as Wyoming, which rely on the healthy crops and livestock. Preventing dust generated from unpaved roads not only helps the environment, but also can reduce costs for farmers and ranchers.

Particles carried over long distances by wind can also be deposited in bodies of water. The effects of this settling include "making lakes and streams acidic, and changing the nutrient balance in coastal waters and large river basins" (USEPA, 2013). With the Midwest region being semi-arid, clean water is considered a precious resource. Dust pollution can have a detrimental effect on clean water, and necessary measures are required to reduce this pollution.

In addition to the environmental damage associated with dust generation, there is also an economic impact. When fine particles are generated into the air from an unpaved road, they are removed from the soil composition of the roadway. The fine material on the roadway acts as a binder for larger particles, and when these fine particles are lost to dust generation, the road will begin to deteriorate at an accelerated rate. The deterioration is due to coarser soil material being thrown or washed from the road surface, which causes raveling, rutting, and washboards (Han, 1992). Consequently, the road deteriorates at an accelerated rate until expensive repairs are required. Loss of fines results in higher costs in grading, blading, graveling and patching. Additionally, road deterioration has an effect on user costs, as a road in poor condition will cause more wear and tear on vehicles (Sanders & Addo, 2000)

Road deterioration costs on unpaved roads vary by distress type. Potholes drive 66% of the improvements recommended for county road systems. Rutting is second to potholes in the cost of recommended improvements (Huntington & Ksaibati, 2009). The cost of maintaining and repairing unpaved roads is linked to the loss of fines by dust generation. Therefore, preventing the loss of fines can lead to direct monetary benefits for those maintaining unpaved road networks.

2.2.3 Road Safety

Dust generation can be an issue when large clouds develop behind vehicles, impairing visibility on roadways. Based on testing done during a 2008 study, it was found that the concentration in milligrams per cubic meter (mg/m3) of PM_{10} particles in the air is directly related to visibility. In addition, the study found that road visibility can be classified by the concentration of particles being released (Edvarsson, 2008). Table 2.1 shows the visual assessment classification of vehicle generated dust and corresponding PM_{10} concentrations.

Table 2.1 Visual Classification (Vagverket, 2005)

Class	Visual Methodology	Average PM_{10} Concentration (mg/m^3)
1	No dust	< 0.5
2	Small amount of dust	0.5 to < 1.5
3	Impaired visibility	1.5 to < 4.0
4	Visibility is critically reduced	≥ 4.0

As can be seen in Table 2.1, particulate matter in the air can greatly reduce visibility, especially when the concentration is above 1.5 mg/m^3. One study found that during poor visibility conditions, crash rates increased by up to 25 times the normal crash rate (Maze et al., 2006).

In addition to reducing visibility, dust generation can result in road defects, which are hazardous to drivers. One study found that when ranking the accident potential of each type of defect, "dustiness, erodibility, raveling, and corrugating are critical defects that control the functionality of roads" (Thompson & Visser, 1999). Crash rates will increase on unpaved roads in poor condition. This poor condition is a direct result of the loss of fine materials. This demonstrates that reducing the loss of fines can improve the condition and performance of a road, and ultimately make it safer for drivers.

2.2.4 Federal Regulation

The size of the particle is directly linked to its ability to cause health problems. The EPA defines inhalable coarse particles as those between 2.5 and 10 micrometers. The EPA is concerned about this range of size, as those are the particles that generally pass through the throat and nose and enter the lungs. Once the particles are inhaled, they can affect the heart and lungs and result in serious health problems (USEPA, 2013).

The Clean Air Act, last amended in 1990, requires the EPA to regulate emissions released into the atmosphere. The regulations are set forth in the National Ambient Air Quality Standards (NAAQS). Included in the NAAQS are regulations on the emission of particulate matter (PM). The regulations set **forth by the EPA are displayed in Table 2.2.**

Table 2.2 Particle Pollution Regulation (NAAQS, 2014)

Pollutant [final rule cite]		Primary/ Secondary	Averaging Time	Level	Form
Particle Pollution Dec 14, 2012	$PM_{2.5}$	primary	annual	0.012 mg/m^3	annual mean, averaged over 3 years
		secondary	annual	0.015 mg/m^3	annual mean, averaged over 3 years
		primary and secondary	24-hour	0.035 mg/m^3	98th percentile, averaged over 3 years
	PM_{10}	primary and secondary	24-hour	0.150 mg/m^3	Not to be exceeded more than once per year on average over 3 years

Primary standards provide public health protection, including protecting the health of "sensitive" populations, such as children, the elderly, and people suffering from respiratory diseases. Secondary standards provide public welfare protection, including protection against decreased visibility and damage to animals, crops, vegetation, and buildings (NAAQS, 2014).

2.3 Dust Suppressant Benefits

A road surface that remains tightly bound will generally require significantly less maintenance. Dust suppressants provide an excellent way to keep the road surface tightly bound (Skorseth & Ali, 2000). The most common type of maintenance performed on unpaved roads is blading. Applying an appropriate type of dust suppressant with the correct application techniques can greatly reduce the need for blade maintenance. This ultimately saves money in labor and equipment costs.

A 2007 study determined how much the use of dust suppressants reduced the need for blade maintenance. The study results indicated that dust suppressants have a significant effect on the amount of blade maintenance needed. Blading was needed on treated sections after 25,500 vehicles and on untreated sections after 3,200 vehicles. This indicated that treated roads lasted about eight times longer on average than untreated sections (Monlux & Mitchell, 2007). Table 2.3 shows the results of this study.

Table 2.3 Unpaved Road Life Ratios (Monlux & Mitchell, 2007)

Project	Traffic Volume Prior to Blading Needed		Life Ratio
	Treated	Untreated	
Trout Creek	21,000	2,000	11
Tucannon	50,000	10,000	5
Miller Lake	10,200	2,800	4
Williamson	9,000	1,200	8
Wickiup	32,000	3,000	11
Conklin	17,000	3,000	6
Payette	52,500	5,000	11
East Fork	50,000	6,700	7
South Side	12,000	700	17
South Side II	20,000	350	57
Deer Creek	22,000	2,700	8
Snow Creek	11,000	1,000	11
Average	25,558	3,204	8

As can be seen from Table 2.3, the life ratio benefit seen with dust treatment can differ depending on the road. Treatment performance varies based on the exact conditions in which it is applied. However, data consistently show that roads treated with dust suppressants perform better than untreated roads (Johnson & Olson, 2009). Reducing road deterioration through dust suppressants saves local entities money in maintenance costs. Road users also benefit, as vehicles will not deteriorate as quickly on a well maintained road surface.

Reducing dust also reduces PM_{10} particles in the air. This means safer air to breathe for both humans and animals (Gravel Road Manual). A cost benefit analysis study found that reducing the particulate matter in the air can result in substantial health cost savings (Ostro & Chestnut, 1998). The decrease in particulate matter in the air will result in healthier and safer air to breath for residents. In addition, reducing particulate matter will help livestock and other animals, which many Wyoming residents rely on for income.

Reduced visibility is one of the major safety hazards associated with dust on unpaved roads, and is directly combated by the use of dust suppressants (Rushing & Tingle, 2007). Reduced perception reaction time resulting from poor visibility is a major contributing factor to traffic accidents (Hills, 1980). Increasing visibility (and thus perception reaction time) with the use of suppressants leads to much safer conditions by giving drivers time to react to obstacles they might encounter while driving.

When a dust control product is used, the fine material in the road cannot lift away, and reduction in loss of fines means stone- and sand-sized particles remain embedded. Loose stone and sand can lead to distresses such as washboarding and reduced skid resistance. Distresses on a road are both a safety and economical concern (Skorseth & Ali, 2009). Eliminating distresses on a road will make it safer for vehicles. This means a reduction in the crash rate and an overall safer experience for drivers, as a direct result of dust suppression.

2.3.1 Safety Concerns

While the use of dust suppressants has many safety benefits, there are some drawbacks. It has been found that the use of suppressants can lower the coefficient of friction between tires and the roadway. This can lead to the road being more slippery, especially when wet (Vestola et al., 2006). A reduced friction factor will reduce the grip between the tires and the roadway. This can lead to uncontrolled sliding of vehicles, which can be very hazardous.

The most common dust suppressant type used in the United States is chloride salt (Amato et al., 2010). In most circumstances, chlorides are the most cost effective means of achieving dust control. However, chloride solutions can create an invisible film on the roadway that will be slippery in certain weather conditions (Mortimer & Ludema, 1972). These films usually develop when the road becomes wet. It is important to determine if treatments will cause slippery conditions, and to provide signage to warn drivers of the possible hazard. See Figure 2.1.

Suppressants can also negatively impact vehicle performance characteristics. Studies have found that chemicals from the suppressants can form a thin layer between the brake discs and the brake pads on a vehicle (Vestola et al., 2006). This can lead to ineffective braking, which can be very dangerous for road users. These safety factors should be considered when applying suppressants to unpaved roads.

Figure 2.2 Warning sign for slippery conditions

2.4 Type of Dust Suppressant

Dust control products are used frequently throughout the United States and come in many different forms. Water, calcium chloride, magnesium chloride, soybean oil, and polymers are the most common products used (Morgan et al., 2005). Each of these suppressant types are sold commercially, and advertised for their usefulness at reducing dust emissions. The substances that comprise each type of suppressant vary, as well as the method by which they provide dust suppression. Information on methodology for application to get the best results with the product is typically provided by the manufacturer (Rushing & Newman, 2011).

2.4.1 Water

The most commonly used dust suppressant is water, which provides dust suppression by creating cohesion between small soil particles. Water between individual soil particles binds the particles together, so they cannot be released into the air as dust. The water also creates a negative pore pressure between particles, which adds to their cohesion (Epps and Ehsan, 2002). The effectiveness of water, as with any dust suppressant, depends on the type of soil it is used on. The clay content in the soil will have an effect on how well the water creates negative pore pressures.

Treating a road with water is considered a short-term and expensive means of dust reduction. While water itself is not generally very costly, transportation and application costs can be expensive. Also, applying water can cause a road to deteriorate at a faster rate, which is counterproductive to the goal of dust suppressants. Deterioration occurs from fines being pumped to the surface of the road, leading to erosion and creation of potholes (Jones, 2014). While water can be used for short-term suppression, it is not used in Wyoming with CMAQ funds due to the adverse road effects it can cause.

2.4.2 Chlorides

Nationwide, chlorides are the most common dust suppressant used. They fall into three main categories: calcium chloride ($CaCl_2$), magnesium chloride ($MgCl_2$), and sodium chloride (road salt). Sodium chloride is used more often in winter applications to reduce ice on roads, and is not considered an effective dust suppressant. When used properly, $CaCl_2$ and $MgCl_2$ are very effective at reducing dust concentration (Gravel Road Manual, 2000). These products are easy to use and do not require specialized training or experience. They have been used in the United States since as early as 1907 for dust suppressant applications (Jones, 2014). The performance of chloride salt and the ease of its application make it cost effective in dust reduction applications.

Chlorides are water absorbing chemicals that work by drawing in moisture from the air. When applied, they keep the road surface constantly damp (Gravel Road Manual, 2000). By keeping the road surface wet, chlorides bind the small soil particles together, keeping them in place. Chlorides also have several other properties that make them effective as dust suppressants. The chlorides have been found to increase the surface tension between soil particles, causing them to bind together more tightly. Additionally, chloride salts evaporate slower than water due to a lower vapor pressure. This means they will last longer in hot conditions than a water treatment. Finally, salt solutions have positive cations, which can flocculate particles, reducing the amount of small particles that can be lifted into the air as dust (Epps & Ehsan, 2002).

Of all water absorbing suppressants, $CaCl_2$ and $MgCl_2$ are considered to be the most effective. Their ease of application, low cost, and short- and long-term effectiveness make them optimal for dust suppressant application. $CaCl_2$ and $MgCl_2$ are utilized on road surfaces either as solutions dissolved in water or dry flakes (Edvardsson, 2009). Many studies have been conducted to determine if either $CaCl_2$ or $MgCl_2$ is preferable over the other. The results often contradict each other, with some suggesting that $MgCl_2$ has better attributes, while others find $CaCl_2$ to be a more effective dust suppressant (Rushing & Tingle, 2007). Some field studies have indicated that roads treated with $MgCl_2$ tend to need reapplication of the product sooner than those treated with $CaCl_2$ (Epps and Ehsan, 2002). These contradictory findings seem to show that suppressant effectiveness is dependent on many different variables, and the preferable suppressant type will differ depending on each unique situation.

Since they are water absorbing, the effectiveness of chloride suppressants is dependent on the amount of moisture in the air. The greater humidity, the greater the amount of moisture absorbed by the salt (Epps & Ehsan, 2002). A chloride's performance is also dependent on factors such as temperature and traffic characteristics. As could be expected, a suppressant used on a high volume road will deteriorate quicker than one used in a low volume area. Depending on conditions, a chloride suppressant will typically have an effective duration of 6 to 12 months (WisDOT, 1997).

While chlorides are widely considered the most cost effective method for dust control, they do have some limitations. As noted previously, they are dependent on atmospheric humidity so they must be used at certain humidity levels. Also, they can cause slippery conditions if they become saturated with water. This can cause dangerous conditions for road users. They can also create a crust over the road, which, when broken up, can reduce road performance (Jones, 2014).

2.4.3 Polymers

Another common type of dust suppressant used in the United States is polymer emulsions. These suppressants are typically either vinyl acetate or acrylic-based in nature, and have been used since the 1980s (Jones, 2014). The polymers are mixed with a surfactant to create an aqueous solution. The solution generally contains about 50% polymer particles by weight (Rushing & Newman, 2011). As the water in the solution evaporates, the polymers bind together to form a film over the road. This film, or polymer matrix, holds the soil in place and does not allow dust to escape. The polymers generally will bind well to the soil, and have a high tensile and flex strength. They are also water resistant, which means they will not wash away during periods of high precipitation. Their strength and resistance to water makes this form of dust suppression very effective, with a high longevity.

While effective, polymer emulsions have several limitations. They are not always readily available in all parts of the country, and transportation can be expensive (Rushing & Newman, 2011). Due to their mechanism for dust suppression, they can be harder to maintain than water absorbing products. They are not yet mass produced, making prices higher for these products. Additionally, they are dependent on petroleum-based chemicals, which can make them even more expensive. The performance characteristics of polymers are based on the manufacturing methods used, and can vary by situation (Addo, Sanders, & Chenard, 2004).

2.5 Application Rate

Regardless of the type of suppressant, the application rate used plays a crucial role in the effectiveness. Application rates are typically measured in gallons per square yard (gsy) or liters per square meter (L/m^2). Studies have shown that the effectiveness of a dust suppressant is directly dependent on the application rate it is applied at (Rushing & Newman, 2011). Tests conducted on the subject indicate a statistical difference in performance at higher application rates. Utilizing application rates that are too high will not be cost effective, so determination of optimum rates is important for economically efficient use of suppressants.

The optimum application rate varies depending on the road conditions. Traffic and soil characteristics will have an effect on the application rate necessary for efficient dust suppression.

Studies indicate that desired results can be achieved with application rates between 0.18 and 0.55 gsy (Johnson & Olson, 2009). The desired performance from a suppressant should first be determined. Then the lowest application rate necessary to attain this performance should be used. By using the minimum application rate necessary, the most cost-effective treatment can be attained.

Some dust suppressants have been found to be ineffective at lower application rates. This indicates that it may be necessary to utilize higher amounts of product on the road to achieve required performance (Rushing & Newman, 2011). Utilizing an optimum application rate can greatly reduce yearly costs of dust suppression. When a correct application rate is used, the frequency of costly re-applications is reduced. Safety is also improved, as a suppressant functioning properly will improve visibility. Optimum application rates can be found in lab studies, provided by the manufacturer, or by collection of field data (Edvardsson, 2009).

2.6 Climate

A major factor in dust generation is the area's climate. As expected, areas that experience hot, dry periods are much more prone to dust generation. The climate has a direct influence on the moisture content of the unpaved road surface. Higher moisture contents will generally result in less dust and more effective dust suppressants. Soils with low moisture contents will be much more prone to dust pollution, and water absorbing suppressants will often not function as well (Edvardsson, 2009). Parts of the country with high precipitation will often not require the use of dust suppressants.

The Great Plains region has long stretches of hot, dry weather. For this reason, the region is considered semi-arid. The dry, hot weather results in unpaved roads with very low moisture contents, which are more prone to dust generation, especially during the summer months (Gravel Road Manual, 2010). As part of the Great Plains region, Wyoming's climate is semi-arid with local desert conditions. Wyoming weather is dry and windy in comparison with most of the United States (Curtis & Grimes, 2004).

In addition to temperature and moisture content affecting dust generation, wind often plays a big part. Unpaved roads can generate dust when wind picks up loose particles from the road surface and lifts them into the atmosphere as dust (Epps and Ehsan, 2002). Wyoming often experiences high winds, so much so that the state has gained notoriety for it. During some periods of the year, the wind can reach 30 to 40 mph with gusts of 50 to 60 mph (Curtis & Grimes, 2004). These high wind speeds contribute to dust generation in a big way, and make dust suppression an important part of maintaining unpaved roads in Wyoming.

2.7 Road Surface Characteristics

For any suppressant to be effective, a good road surface prior to application is crucial. Since the suppressants used in Wyoming (chlorides) are water absorbing, they require certain soil conditions. The road surface must have a good gradation with the appropriate amount of fine materials. Soil with some degree of plasticity will also aid the suppressant in keeping the road surface damp, and thus tightly bound. If the correct soil conditions are met, dust suppressants will function for longer periods without the need for reapplication (Gravel Road Manual, 2000).

The percent of fines (material passing the #200 sieve) in the road surface material plays an important role in both dust generation and dust suppression. The fine material in the soil helps hold together larger particles and act as a binder for the road. However, the fine material directly contributes to the amount of dust released from a road (Jones, 2014). The optimum percent of fine material for unpaved roads requiring dust treatment is typically between 5% and 30%. Roads with fines outside this percent range can still receive dust control treatment, but the suppressant will generally not perform as well (WisDOT, 1997).

Clay content is also important in determining how effective a suppressant will be. Soils with higher clay content will bind together better, and form a more cohesive surface for the dust suppressant. To determine the cohesiveness of the soil, liquid limit and plastic limit tests can be performed (Jones, 2014). When the soil is granular with low clay content, it will reduce the effectiveness of the dust suppressant as the small particles will not bind together as well (WisDOT, 1997).

In addition to soil characteristics, road surface quality should be taken into account when considering the most cost-effective use of a dust suppressant. Proper drainage will prevent pooling, which can decrease the effectiveness of suppressants. To achieve proper drainage, a good crown should be shaped into the road prior to dust control treatment. This will make certain that any excess surface water flows off of the road (Epps and Ehsan, 2002). Improper drainage of a road can lead to severe road deformations such as potholes and rutting. Ensuring a road has a good crown will substantially reduce long-term maintenance costs (Skorseth & Ali, 2000). A road that already has a good crown and drainage will hold that shape once a suppressant is applied.

Dust suppressants will be efficient and cost effective on roads that are in good shape to begin with. Proper soil gradation and clay content will ensure that the soil binds together well when a suppressant is applied. Correct shaping of the road will allow for good drainage, which will allow the suppressant to perform for longer without washing away. Suppressants will not solve problems caused by poor construction, bad drainage, or lack of maintenance (WisDOT, 1997).

2.8 Traffic Composition

The traffic composition of an unpaved road is the determining factor in how quickly the road degrades. Along with degradation, the amount of dust generated from a road depends on the traffic composition and vehicle characteristics. Therefore, "understanding vehicle type, size and weight, traveling speed, and volume are essential in any unpaved road maintenance studies" (Addo et al., 2013). By understanding vehicle characteristics, dust volumes and re-application periods for dust suppressants can be estimated.

2.8.1 Vehicle Characteristics

Studies have found that the volume of dust generated from unpaved is affected mainly by vehicle weight and speed. Dust generation has been found to be linearly dependent on these two variables, meaning that as vehicle speed or weight is increased, the amount of dust generated from the road also increases. This linear relationship seems to imply that dust concentrations are affected by vehicle momentum, the combination of weight and speed. Studies show that other vehicle variables, such as wheel and undercarriage size, do not have a substantial effect on dust concentrations (Gillies et al., 2005). Therefore, to predict dust volumes on unpaved roads, focus should be placed on determining average vehicle speed as well as weight composition of vehicles on the road.

A considerable amount of research has been conducted on relating vehicle to dust generation on unpaved roads. Studies show that cutting average vehicle speeds from 40 mph to 35 mph will reduce dust emissions by 40% (WisDOT, 1997). A study conducted in Colorado with the CSU Dustometer dust collection device established a linear relationship between vehicle speed and dust volumes (Sanders & Addo, 2000). As can be seen in Figure 2.2, speed plays an important role in the dust volumes, and as a vehicle increases its speed, higher dust volumes will be generated. These results indicate that speed control, while often neglected on unpaved roads, will greatly reduce the amount of dust generated.

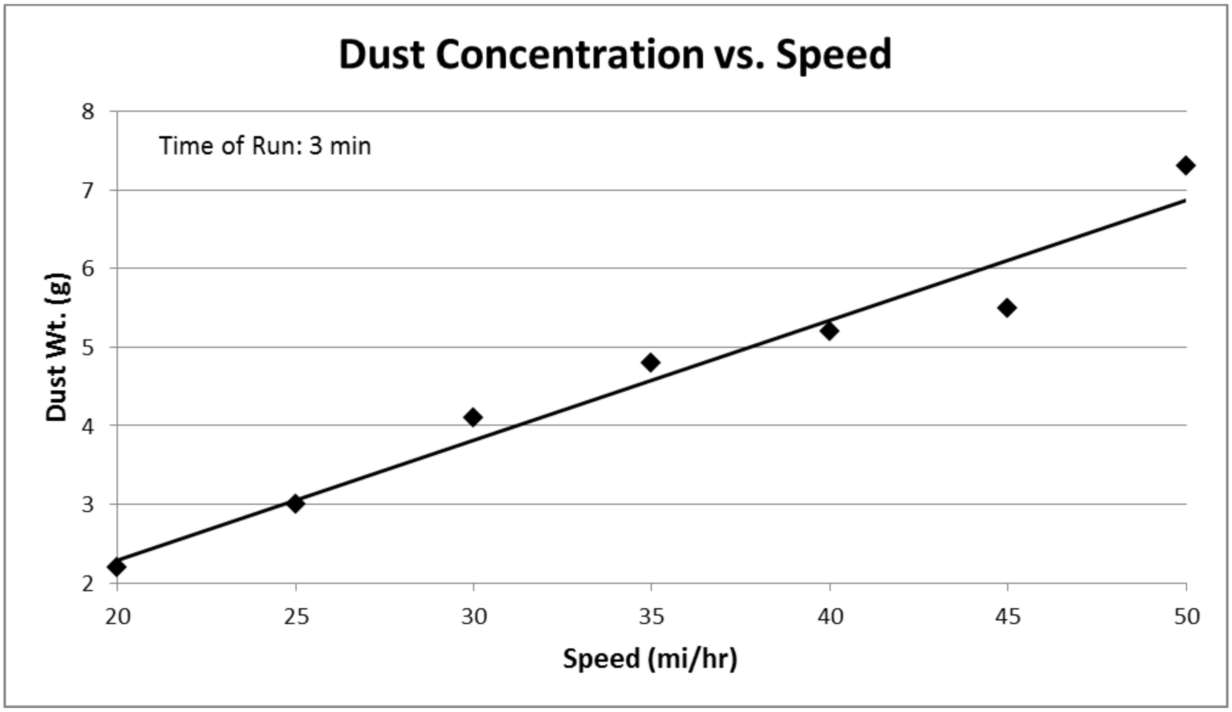

Figure 2.3 Effect of speed on dust generation (Sanders & Addo, 2000)

In addition to speed, vehicle weight is related to dust volumes (Sanders, Ariniello, & Heiden, 1997). Unpaved roads generally contain graded soil material. As a vehicle rolls over the road, a downward force is generated that crushes this graded material. As the soil is crushed and pulverized by vehicles, smaller dust particles will be released from the road. A heavier vehicle will create more downward force and cause higher dust volumes to be generated into the air (Chow et al., 2003). Understanding the weight of vehicles traveling on the road is important in determining dust volumes, as well as how quickly a dust suppressant and the road itself will deteriorate.

2.8.2 Traffic Volume

Traffic volumes on unpaved roads contribute significantly to the amount of dust generated. A road with high vehicle volumes will release more dust, as each vehicle traveling the road generates a certain amount. Traffic volumes also influence the effectiveness of dust suppressants. High-volume roads will generally experience degradation of dust suppressant effectiveness more rapidly than similar low-volume roads. According to the Transportation Research Board, an average daily traffic (ADT) of 500 is the standard acceptable cutoff for cost-effective use of suppressants (TRB, 1980). While a road with an ADT higher than 500 can be treated, the treatment will not be as cost effective. These roads will usually require more reapplications of dust control products as high-volume segments are hard to maintain with temporary dust suppressant products. It is often recommended that more permanent surface treatments be considered for these roads (Han, 1992).

Roads with low vehicle volumes will usually not require the same level of dust control as roads with higher ADTs. Very low volume roads will often not justify the cost of applying a dust control product. The Wisconsin Transportation Research Board recommends dust control products be applied on roads that carry between 15 and 500 vehicles per day on average (WisDOT, 1997). This range provides a good estimate for when dust suppressants will be effective, but the exact cutoff can change depending on the situation. If a road experiences vehicle volumes higher than 500 ADT for only short periods of the year, the use of dust suppressants may be appropriate.

2.9 Dust Measurement Devices

This section contains descriptions of devices commonly used for determining dust concentrations on unpaved roads. The HAZ-Dust EPAM-5000 and the CSU Dustometer are discussed in more detail, as they were used for data collection in this study.

2.9.1 MiniVol PM_{10} Samplers

The MiniVol PM10 Sampler is a pump powered air testing unit. The MiniVol's pump draws air at 5 liters/minute through a particle size separator and then through a 47mm filter. The particle separator can be set to PM_{10} or $PM_{2.5}$ size. The particulates that enter the inlet are deposited on a 47mm filter. Before and after dust is deposited on it, this filter must be weighed with a microbalance accurate to one microgram (Gillies et al., 2009). Figure 2.3 shows the device.

Figure 2.4 MiniVol PM10 Sampler

The MiniVol samplers can be used in combination to determine dust concentrations at different heights above the road. This can be accomplished by setting up towers next to the roads and attaching MinVol samplers at different heights along the tower. This kind of information is useful for determining dust concentrations throughout a dust plume (Etyemezian et al., 2005).

2.9.2 DustTrak II Aerosol Monitor 8350

The DustTrak II Aerosol Monitor 8350 is a battery-operated aerosol particle monitoring device. The device uses a light-scattering laser photometer to determine particle concentrations. It can measure particle concentrations corresponding to PM_1, $PM_{2.5}$, and PM_{10}. The DustTrak has a display screen that shows real-time particle concentrations. It also logs the data in its internal memory (TSI Incorporated, 2015). Figure 2.4 shows the device.

Figure 2.5 DustTrak II 8350

This device is useful as it is applicable to many different situations. It can be used in indoor and outdoor applications. Its construction makes it suitable for harsh outdoor applications such as construction sites. This device is also useful for measuring different kinds of air contaminants, such as fumes, dust, smoke, and mist (TSI Incorporated, 2015).

2.9.3 HAZ-DUST EPAM-5000

In order to determine dust concentrations from unpaved roads, collection equipment that accurately reads the dust volumes being generated must be used. One such device is the Haz-Dust EPAM-5000, which is seen in Figure 2.5. The Haz-Dust is a stationary device that continuously monitors air quality. The device is adaptable in that it can be calibrated for the size of particle desired. As stated in the user guide:

> The Haz-Dust uses the principle of near-forward light scattering of an infrared radiation to immediately and continuously measure the concentration in mg/m^3 of airborne dust particles. This principle utilizes an infrared light source positioned at a 90-degree angle from a photo detector. As the airborne particles enter the infrared beam, they scatter the light. The amount of light received by the photo detector is directly proportional to the aerosol concentration. A unique signal processes internally and compensates for noise and drift. This allows high resolution, low detection limits and excellent base line stability (HAZ-DUST User Guide).

Figure 2.6 HAZ-DUST EPAM 5000

The unit records particle concentrations in milligram per meter cubed. The air is continuously sampled every second, and these data points are stored in the internal memory. The data can then be downloaded to a computer for analysis (HAZ-DUST User Guide). This device is useful as the data it exports can be easily transferred into data analysis software. By placing the Haz-Dust unit on the side of an unpaved road, the dust concentrations can be determined for that roadway.

2.9.4 Colorado State University (CSU) Dustometer

Another device used for determining dust concentrations is the Colorado State University (CSU) Dustometer, which was developed in 1995 during a Mountain Plains Consortium research project (Sanders et al., 2015). The objective for developing this device was to create a piece of equipment that was easy to use, relatively inexpensive, and able to determine the dust concentrations generated from unpaved roads. Development of a device that can accurately determine dust concentrations allows for an effective assessment of different dust suppressants. This can be done by comparing values obtained with the Dustometer before and after a road section is treated with a suppressant. Another advantage of this device is its method of data collection, which determines dust concentrations for a section of road instead of at one single point (Sanders & Addo, 2000).

The CSU Dustometer device consists of (1) a vehicle, (2) electric generator, (3) suction pump, (4) filter box containing a 10 x 8 in. glass fiber filter, (5) metal bracket attached to the bumper of the vehicle, and (6) a flexible tube for connecting the suction pump to the filter box (Sanders & Addo, 2000). The device is attached to the rear bumper of a vehicle for the data collection process. Figure 2.6 shows the CSU Dustometer setup.

Figure 2.7 CSU Dustometer

The device works by sucking air through the filter box. As air is sucked through, dust released from the rear tire is deposited on the filter. This weight of dust on the filter is used to determine the gram per mile (g/mi) of dust for the road. Approximate dimensions for the location of the Dustometer on the rear end of the vehicle are shown in Figure 2.7. The exact dimensions are not as important as keeping the setup consistent for all tests conducted. If the test procedures are standardized in the future, this would greatly help research on road dust (Sanders et al., 2015).

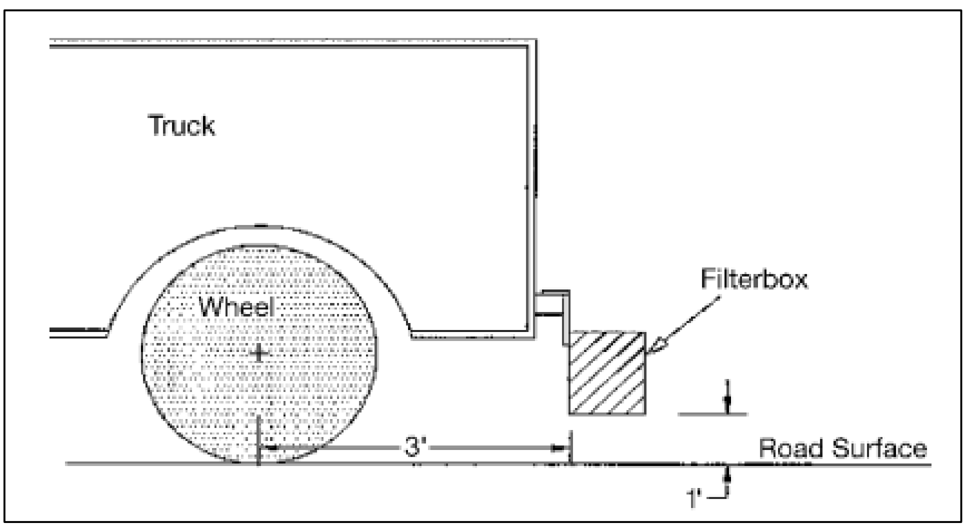

Figure 2.8 Schematic of Dustometer attached to vehicle

The CSU Dustometer is superior to dust collection devices previously used. It is mobile, meaning that it can be moved from one test section to another with ease. Each test with the device can be performed relatively quickly, which makes it easier to collect many data points in a short amount of time (Sanders et al., 2015). Research conducted with the Dustometer indicates it has a high level of precision. Nine replicate tests showed the coefficient of variation was only 7% at speeds of 45 mph. (Sanders & Addo, 2000). The benefits of this device make it suitable for many applications in the field of dust control.

2.10 Chapter Summary

This chapter contained a review of literature pertaining to dust pollution and dust suppression. The literature review shows the damaging effects that dust pollution has on health, safety, and the environment. It also discusses current federal regulations pertaining to particulate matter, and follows with the benefits and concerns associated with using dust suppressants. In addition, the different types of dust suppressants and the types of environments where each is commonly used are discussed.

This chapter also discusses the factors that influence the effectiveness of dust suppressants, including application rate, road surface material and classification, climate, and traffic characteristics. Additionally, several types of equipment that can be used to determine dust concentrations on unpaved roads are identified.

3. METHODOLOGIES

This chapter summarizes the order in which processes were completed for the project. First, the objectives and expected outcomes of the study were established. This is summarized in Chapter 1. Next, a literature review was conducted on relevant material. This literature review helped determine what factors should be considered during data collection. The literature review can be found in Chapter 2. The next three portions of the report are given in three distinct phases.

Phase 1 was an exploration of the EPAM-5000 dust collection device. The device was used to test several roads, then the results were used to establish methodologies for its best use. This included how to obtain an average dust concentration from a road with the device, what the optimum data collection period is, and where to place the device on the road for accurate readings.

Phase 2 was a correlation between the CSU Dustometer and the EPAM-5000. This was done by collecting data from roads around Albany County with both devices, then analyzing the collected data. The data analysis included a statistical analysis to identify a regression model correlating the two devices.

Phase 3 was the determination of CMAQ funds effectiveness in Wyoming. This included data collection from various counties around the state, and analysis of the data collected. Additional information provided by counties, such as cost of treatment, is included in the data analysis. This phase also included a statistical analysis to establish linear regression models between dust concentrations and various roadway characteristics.

Upon completion of the three phases, conclusions could be reached on appropriate methods for data collection, and the effectiveness of CMAQ funds in Wyoming. Additional recommendations could be made for future studies. Figure 3.1 shows the report organization.

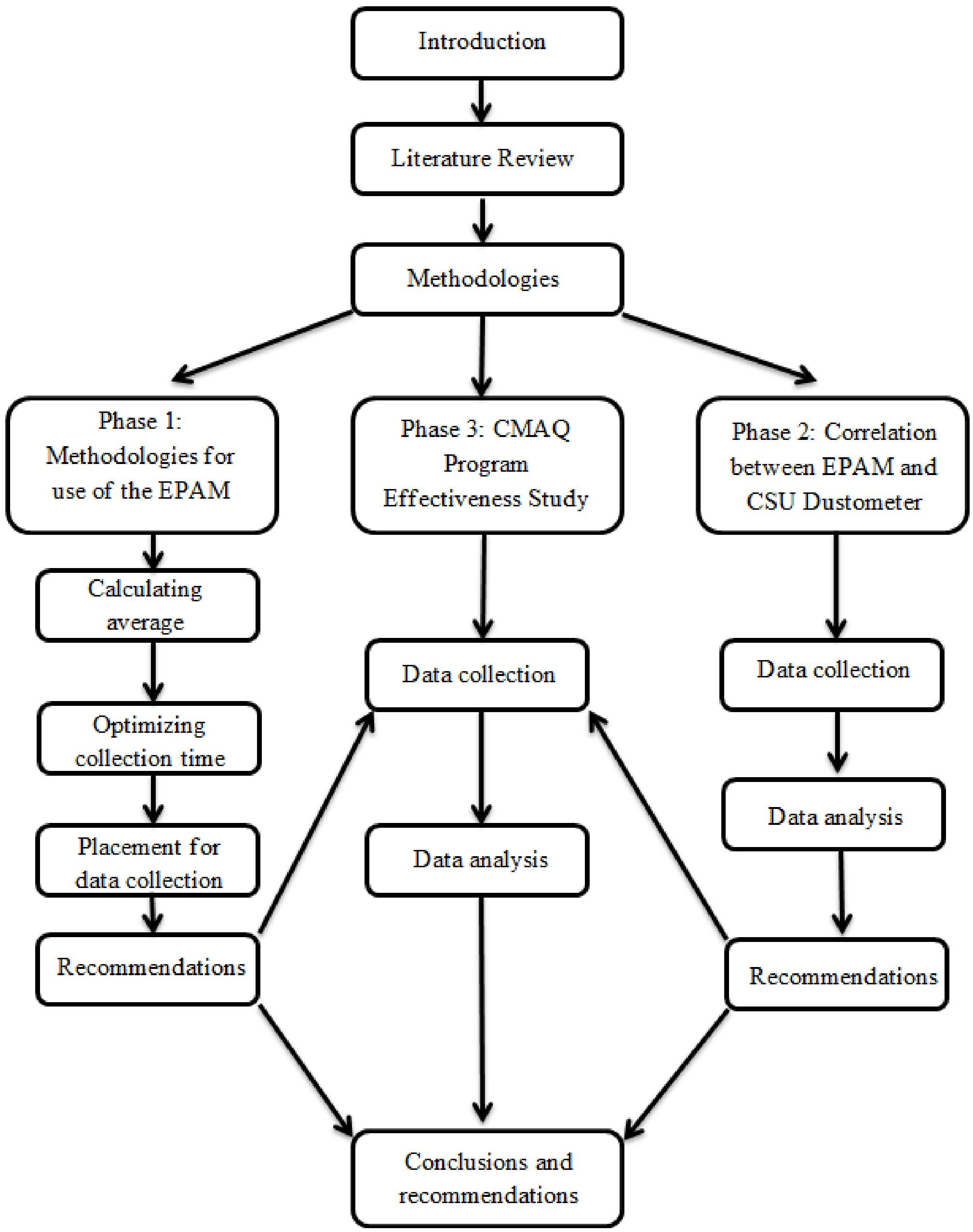

Figure 3.9 Report organization

4. PHASE 1: METHODOLOGIES FOR USE OF THE EPAM-5000

4.1 Introduction

This chapter discusses methodologies developed for use of the EPAM-5000 monitoring device. These included the most efficient ways of analyzing data, optimizing data collection time periods, and procedures for collecting data with the device. These methodologies were developed to help in future assessment of dust suppressant effectiveness, as they provide a blueprint for the best ways of finding and analyzing the desired data with the EPAM-5000.

This chapter contains explanations of the problems encountered, and justification for the methodologies that were developed to overcome said problems. Each section of this chapter includes recommendations on the best way to apply the methodology. It is believed the methodologies will aid in future use of the EPAM-5000, and ultimately help in determining the effectiveness of CMAQ funds in Wyoming. The data used in this section can be found in Appendix A.

4.2 Calculating Average PM10 Concentration from Haz-Dust EPAM-5000

The EPAM dust box continuously monitors air quality and reports the concentration of particles in the air in milligram per cubic meter (mg/m^3). The output of the EPAM-5000 is a running list of concentrations sorted by time. The data are transferred from the box into a program called EDC DustComm Pro. Figure 4.1 displays data transferred from the EPAM unit into the DustComm software.

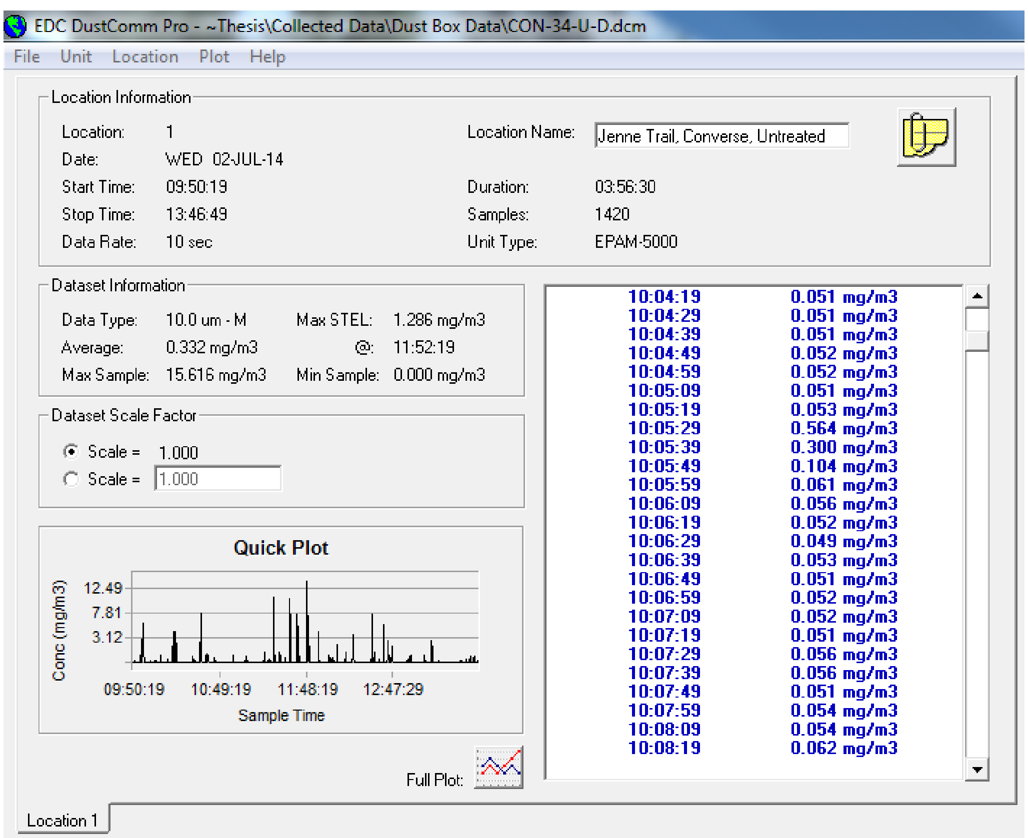

Figure 4.10 DustComm output

This data can be used to find the average concentration of particles generated by vehicles traveling an unpaved road at a particular location. The DustComm software itself provides only limited statistical analyses, such as max concentration, minimum concentration, and average concentration of all data points. However, by exporting the results to Excel, more in-depth analysis can be conducted. There are three methods for calculating the average concentration researched in this study. The first method is by simply calculating the average of all data points collected by the dust box. The second is by calculating the average of all data points above a certain set threshold. The third method is by calculating the average of all peak values observed in the data. These three methods vary both in ease of calculating the average and in usefulness of the resulting average.

4.2.1 Method 1: Average of All Data Points

This method generates an average by taking into account all data points recorded on the EPAM. It is the easiest to calculate, as the DustComm software automatically generates this value when the box is connected to a computer. This value is also easy to calculate when the data are exported into Excel by selecting the entire list and using the AVERAGE( ) function. Figure 4.2 displays a graph of the concentrations recorded on an unpaved road.

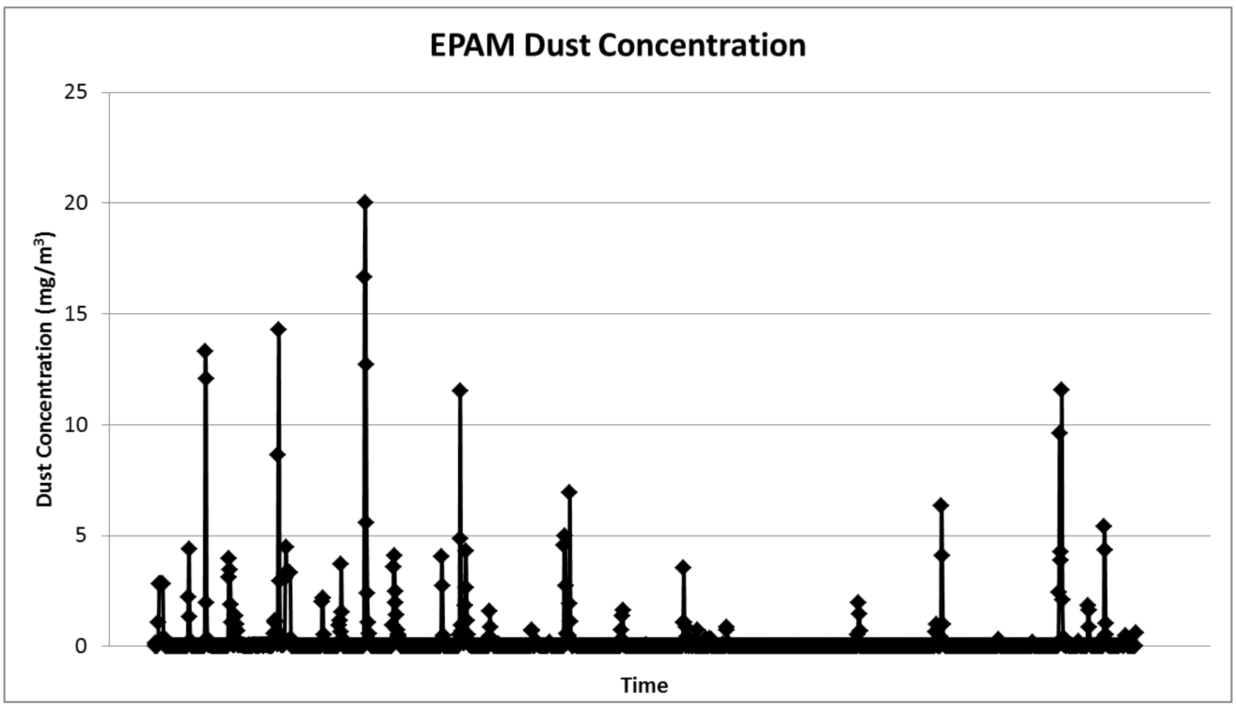

Figure 4.11 Concentrations with all data points used for average

This method takes the average of all data points shown in Figure 4.2, which shows that during periods when no vehicles are traveling the road, the dust concentrations are very low. With this method, all of these low-value data points are used in calculating the average. While this makes it easy to calculate the average, it has the drawback of not showing an average dust concentration from vehicles driving on the unpaved section. So this method is not good for getting a representative average of the dust concentrations generated by vehicles.

4.2.2 Method 2: Average of Data Points above Threshold

Method 2 generates an average by taking into account all data points above a certain threshold. This attempts to eliminate the time periods during which no vehicles are traveling on the road and results in a better estimation of dust concentrations generated by vehicle traffic. Figure 4.3 displays a graph of concentrations on an unpaved road along with the threshold line.

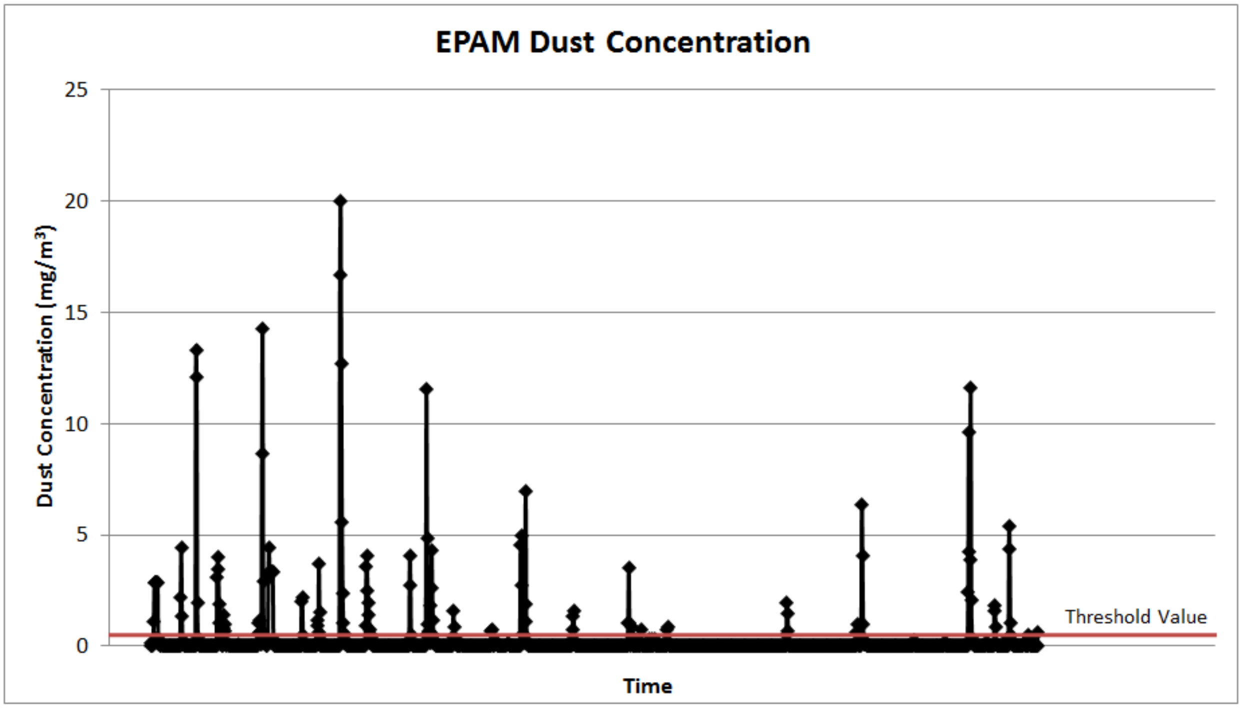

Figure 4.12 Concentrations with threshold data points used for average

As can be seen from Figure 4.3, this method eliminates the low-value data points and calculates an average concentration using only data points from times when vehicles cause spikes in the dust concentration. This value cannot be generated in the DustComm software and requires the data to be exported into Excel. Once in Excel, the average can easily be obtained by sorting the list of data points from highest to lowest. Once this is done, all data points greater than the threshold value are selected and used in calculating the average concentration. A drawback to this method is that one vehicle driving on the road can result in several data points recorded by the EPAM unit. All of these data points that lie above the threshold are used in calculating the average, so one vehicle can influence the data.

4.2.3 Method 3: Average of Peak Data Points

Method 3 takes into account only the peak data points that can be observed when a vehicle traveled the road. These peaks can easily be seen when the data recorded by the dust box are graphed. Figure 4.4 displays the graphed data from an unpaved road with data points used to calculate the average circled.

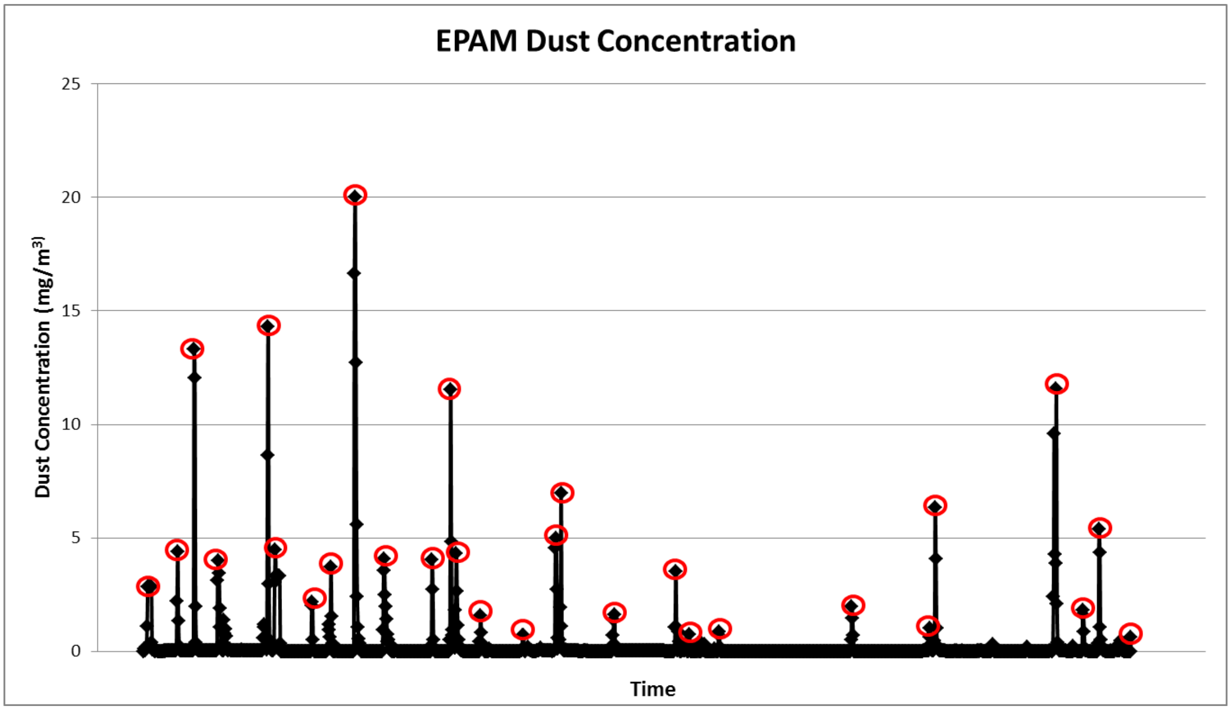

Figure 4.13 Concentrations with peak data points used for average

As can be seen from Figure 4.4, spikes in concentration occur when vehicles pass the device. This method takes the concentration at the peak of each of these spikes and averages them. This results in the average particle concentration generated by vehicles travelling the unpaved road. The drawback to this method is that it is time consuming. The DustComm software does not calculate this average and Excel has no easy way of finding each peak value. The necessary method is to place the mouse cursor on each individual data point desired on the graph and read the value. This value then must be keyed into a cell. When all peak values have been typed in, an average can be generated.

4.2.4 Comparison of Methods

Each of the three methods described above results in a different value for the average dust concentration generated by vehicles on an unpaved road. The average concentration using each of the three methods were applied to 14 road sections from this study. Table 4.1 displays the results of the different methods.

Table 4.4 Comparison of Methods for Calculating EPAM Average

County	Road	Method 1: All Data Points		Method 2: Data Points Above Threshold		Method 3: Data Points at Peaks	
		Average	Std. Dev.	Average	Std. Dev.	Average	Std. Dev.
Albany	Construction Road	0.516	1.495	2.674	2.978	5.947	3.489
	Burbaker	0.074	0.253	1.188	0.554	1.424	0.687
	Hornsby	0.112	0.35	1.246	0.468	1.525	0.423
	Reservoir	0.053	0.303	2.003	1.584	2.668	1.739
Converse	Jenne Trail (Untreated)	0.332	1.275	2.674	2.962	3.592	3.75
	Jene Trail (Treated)	0.012	0.014	0.029	0.018	0.067	0.038
Lincoln	Muddy Creek (Untreated)	0.044	0.15	1.227	0.628	1.05	0.861
Crook	D-Road (Untreated)	0.097	0.437	1.779	1.277	2.282	1.53
	D-Road (Treated)	0.21	0.023	0.024	0.024	0.245	0.245
Campbell	Moore (Untreated)	0.282	1.32	3.043	3.481	6.063	4.596
	Moore (Treated)	0.118	0.236	0.141	0.254	0.219	0.187
	Clarkelen (Untreated)	0.126	0.422	1.433	0.898	1.776	0.957
	Clarkelen (Treated)	0.011	0.011	0.02	0.012	0.031	0.024
	Cosner (Untreated)	0.331	0.827	1.846	1.359	2.651	1.642

As shown in Table 4.1, using Method 1 to average all data points results in a very low average concentration. As discussed earlier, this is due to the average containing data points during times when no vehicles were traveling the road. While this method is easy to calculate, it does not give a representative estimation of the amount of dust generated by the presence vehicles traveling the road. For this reason, Method 1 is not recommended as a viable way of analyzing the data collected by the EPAM-5000.

Using Method 2 to average all data points above a set threshold, results in a higher average concentration than method 1. This is due to periods of no traffic being eliminated by the threshold value. This method is easy to calculate, and results in a value that makes sense and can be justified. Due to the elimination of low data points, and the ease with which the average can be calculated, Method 2 is recommended as a viable way of analyzing the data collected by the EPAM-5000.

Using Method 3 to analyze only the peak data points resulted in the highest average of the three methods. This could be expected, as averaging only the peaks will result in the highest possible value. While this method is perhaps the best way of determining average dust concentrations from vehicles, there is no easy way of finding the average using Excel. A method that can be easily implemented by counties is desired. For this reason, Method 3 is not recommended as a viable way of analyzing the data collected by the EPAM-5000.

4.2.5 Summary and Recommendations

Method 1: Average of all data points

- Pros
  - Easy to Calculate

- Cons
  - Not representative of vehicle dust, because it includes periods of no traffic in average

Method 2: Average of data points above threshold

- Pros
  - More representative of vehicle dust, because it eliminates periods of no traffic
  - Fairly easy to calculate

- Cons
  - One vehicle can generate several points above threshold

Method 3: Average of peak data points

- Pros
  - Average is representative of vehicle dust concentrations, because it eliminates periods of no traffic and eliminates multiple data points from one vehicle

- Cons
  - Time consuming

Due to a low value using Method 1 of averaging all data points, it is not recommended for use for determining an average value since it includes many time points with no vehicles. Due to the time consuming nature of Method 3 of averaging only the peak data points, it is also not recommended for use in determining an average value. Method 2 of averaging values above a set threshold provides a representative and time efficient way of determining the average value. For these reasons, Method 2, "the threshold method," is recommended for finding the average concentrations from the EPAM-5000. All data analysis performed in this study on the EPAM was done using the threshold method.

4.3 Optimizing Data Collection Time for the EPAM-5000

As part of the study, the results from the EPAM-5000 were analyzed to determine the optimum time period for data collection. This was done to determine the most effective length of time for finding an average concentration from a road, while keeping the collection period time efficient. All data analysis and averages from the EPAM were done using the threshold model described in Section 4.2.

4.3.1 Data Collection and Analysis

During the course of the first summer of data collection, five roads were analyzed using the EPAM-5000. The data collection period for each road was four hours long, during which time the EPAM unit continuously monitored the air quality. This four-hour period was conducted twice on each road, once before the road was treated and again after treatment. This resulted in an average concentration of dust for each four-hour data collection period.

The results from the EPAM were downloaded into Excel. The average dust concentration for the four-hour data collection period was found for each road. Then the average dust concentration for the first three hours of data collection was found for each road. This was repeated for the second three hours, the first two hours, the middle two hours, and the final two hours of data. This was done to compare the average obtained for the full four hours to the other shorter time periods to determine if there was a statistically significant difference between them.

A two tailed t-test was performed between each group at a 95% confidence level (α=0.05) to determine if the averages of the time periods were statistically different. The Pearson correlation coefficient was also calculated for each group. Table 4.2 shows an example of two groups compared.

Table 4.5 Example of Two Comparison Groups

4 hours vs. First 3 Hours					
	Location				
	1	2	3	4	5
Average of 4 hour collection period (mg/m^3)	1.433	1.846	3.043	2.674	1.779
Average of first 3 hours collection period (mg/m^3)	1.453	1.838	2.989	2.887	1.84

Similar tables were formed for comparison between each group. The two-hour time periods were compared with the four-hour and three-hour time periods and to each other. The three-hour time periods were compared with the four-hour time period and two-hour time periods and to each other. The results of these tests are summarized in the following section.

4.3.2 Results and Recommendations

Comparing each time period, the results are shown in Table 4.3. If the t value is greater than the t critical value of 2.78, it indicates there is a statistically significant difference between the mean values.

Table 4.6 Time Optimization Results

t-Test: Paired Two Sample for Means		
α = 0.05, $t_{critical}$=2.76	Untreated	Treated
Time Periods Compared	|t|	|t|
4 hours vs first 3 hours	1.01	1.88
4 hours vs last 3 hours	0.54	2.04
4 hours vs first 2 hours	0.21	4.79
4 hours vs middle 2 hours	0.15	2.25
4 hours vs last 2 hours	1.46	0.83
First 3 hours vs. last 3 hours	1.11	2.41
First 3 hours vs. first 2 hours	0.49	2.91
First 3 hours vs. middle 2 hours	0.40	2.81
First 3 hours vs. last 2 hours	2.10	0.79
Last 3 hours vs. first 2 hours	0.26	2.61
Last 3 hours vs. middle 2 hours	0.31	1.03
Last 3 hours vs. last 2 hours	0.98	0.99
Indicates time periods compared were statistically different		

The results of the t-tests found that none of the averages from the three-hour periods were significantly different than the averages from the four-hour collection periods. This indicated a data collection period of three hours would result in the same average dust concentrations as those obtained from the four-hour collection period.

The results of the t-tests found that some of the averages from the two-hour periods were significantly different than the averages from the four-hour and three-hour collection periods for treated roads. This indicated a data collection period of two hours would result in different average dust concentrations than those obtained from the four-hour collection period for some treated roads.

From the results of the statistical analysis, it was determined that a three-hour data collection period would yield results not significantly different than a four-hour data collection period. However, a two-hour data collection period would yield results significantly different than the four-hour data collection period. Based on these results, a three-hour data collection period is recommended for the EPAM-5000 to obtain accurate results and to optimize the amount of time that data are collected.

4.4 EPAM-5000 Placement

As discussed in previous sections, the EPAM-5000 is a stationary unit that continuously monitors air quality. Since the unit is stationary, placement of the device is important for accurate data collection. It is realized that the closer the unit is to the road, the more accurate the measurements can be, since dust concentrations will be read before they disperse into the air. For this reason, the unit should be placed within one to two feet of the side of the road. If necessary, a marker should be placed next to the device so vehicles do not drive over it.

For the summer of 2014, only one EPAM device was available for data collection. If conditions were windy, it was placed on the downwind side of the road. This ensured that as dust was generated from the road it would pass over the box, and readings would accurately display the concentration of particles being released from the road. If conditions were calm with no wind, best judgment was used to decide which side of the road the unit was placed on.

For the 2015 data collection period, two EPAM devices were available for data collection. This allowed one device to be placed on each side of the road section being tested. The boxes were placed directly across from each other on each side of the road, approximately one to two feet from the edge of the traveled way. This ensured that regardless of wind conditions, the dust concentrations coming off the road could be accurately measured.

4.4.1 EPAM-5000 Placement Recommendations

For data collection, EPAM devices should be placed within one to two feet of the edge of the traveled way. If only one EPAM device is available for data collection, wind conditions should be assessed before the box is placed. The box should then be placed on the downwind side of the road, ensuring that all dust coming off the road passes over the monitoring device. If two EPAM devices are available for data collection, one should be placed on each side of the road, resulting in dust concentration readings regardless of wind. This is the recommended method for data collection with the EPAM unit.

4.5 Chapter Summary

This chapter contained explanations of methodologies developed for data collection and analysis with the EPAM-5000. The first methodology discussed was determining the average dust concentration from the results obtained from the EPAM-5000. It was determined that the most time efficient way of getting an average while still getting a representative average was to set a threshold value and take the average of all values above this threshold. This was followed by the methodology for optimizing data collection time with the device. It was determined through statistical analysis that the optimum data collection period is three hours for each road section tested. Finally, placement of the EPAM unit for data collection was discussed. It was determined that the most accurate results are collected from placing one unit on each side of the test section. However, if only one EPAM unit is available, the most accurate results will be found from placing it on the downwind side of the test section.

The methodologies developed in this section will help in future data collection and analysis. Specifically, these methods will provide the best assessment of the cost effectiveness of CMAQ funds. The methods developed are applicable regardless of region or conditions. By using the procedures described in this section, data collection with the EPAM-5000 will be accurate and time efficient. It is strongly recommended that these methods be used in future assessments of suppressant effectiveness.

5. PHASE 2: CORRELATION OF EPAM-5000 AND CSU DUSTOMETER

5.1 Introduction

As part of the study, the CSU Dustometer and the HAZ-Dust EPAM-5000 were compared (Figure 5.1). The CSU Dustometer is a mobile unit that is attached to a vehicle and collects dust as the vehicle drives along an unpaved road. The result is the concentration of dust released from a road in grams per mile (g/mile). The Haz-Dust unit is a stationary unit that is set on the side of an unpaved road, and the result is the concentration of dust released from a road in milligrams per cubic meter (mg/m3). The difference in collection techniques, as well as the units the concentration are reported in, makes comparison between the two devices difficult. In addition to finding a correlation, this study helped in determining if one device was preferable over the other in terms of accuracy of collection and usefulness of resulting data.

CSU Dustometer HAZ-Dust EPAM-5000

Figure 5.14 Dust Collection Devices

5.2 Data Collection

Ten roads that had not been treated with any type of dust suppressant were selected from different locations around Albany County, Wyoming. In addition, four roads that had been recently treated with dust suppressants were selected. These roads were intended to have varying characteristics of soil and moisture content.

For each road, the EPAM-5000 device was placed on the side of the traveled way and allowed to run while three passes were made with the CSU Dustometer. Wind and temperature readings were collected after each pass made with the CSU Dustometer. Finally, soil and moisture samples were collected from the road. This process was repeated for each of the test sections. Data collected for this phase are summarized in Appendix B.

5.3 Data Analysis

During analysis, it was observed that the CSU Dustometer recorded high dust concentrations on the four roads treated with dust suppressants. These results contradicted the results from the EPAM-5000 monitoring device, as well as from a visual inspection of the amount of dust coming off the road. It was determined through visual inspection of the particles collected on the Dustometer filter that the device was picking up larger particles that were not actually dust being released into the air. These particles were being picked up by the tire of the testing vehicle and deposited on the filter, resulting in a higher reading of grams per mile of dust. This was based on testing done using a #38 screen over the Dustometer filter box. Attempting to fix this issue due to larger particles being picked up, a finer screen (#200) was placed over the filter box and tests on the four treated road sections, as well as two additional treated roads, were repeated. Table 5.1 shows the results of these tests.

Table 5.7 Dustometer Concentrations on Treated Roads

Screen Size	Test Section	Average Concentration from EPAM-5000 (mg/m^3)	Average Concentration from CSU Dustometer (g/mile)
#38 Screen	CR-51	0.029	0.82
	Mason ln	0.051	2.59
	Curtis Rd	0.028	1.02
	Sand Creek	0.016	0.27
#200 Screen	Mason ln	0.033	1.15
	Curtis Rd	0.023	2.03
	Sand Creek	0.040	0.90
	Brubaker	0.059	0.31
	Sand Creek (2)	0.032	1.52

As can be seen from Table 5.1, even with a finer screen size, the Dustometer still had high readings for dust concentrations. Since using a finer screen did not fix this problem, it was determined that the nature of the device allowed it to pick up particles heavier than those that might actually be released onto the air. At this point, it was realized that a limitation of the CSU Dustometer was it does not give an accurate reading of dust concentrations on roads treated with dust suppressants.

5.4 Correlation using #38 Screen

As noted in the previous section, the results from the Dustometer are not accurate after a road has been treated. For this reason, only the data collected from untreated roads were used in establishing a correlation between the two devices. Using the #38 Screen in the Dustometer, 10 untreated test sections were evaluated with both devices. The average concentration from the EPAM-5000 was found using the threshold model described in Chapter 3. Table 5.2 shows the data collected with the two devices.

Table 5.8 Dust Concentrations on Untreated Roads

Road	EPAM-5000 Concentration (mg/m^3)	Dustometer Concentration (g/mi)
Construction Road	2.674	3.31
Brubaker	1.188	0.67
Hornsby	1.246	1.15
Reservoir	2.003	2.17
E. Curtis	1.817	2.03
Welsh	1.775	3.25
310 Mason Ln	0.820	0.90
Brubaker (2)	0.411	0.31
Sand Creek	1.092	1.52
CR - 51	1.838	2.60

The results of the data collection were evaluated in the statistical analysis software "R" to determine if a correlation existed between the two dust monitoring devices. The R lm() function was used to fit a linear model to the set of data points. Theoretically, the model should pass through the point (0,0). However, constraining a regression model to pass through the origin can result in a poor fit. For this reason, the model was not constrained to pass through the origin. This linear model's results had an adjusted R-squared value of 0.794 and a p-value of 5.4e-04, indicating evidence of a strong correlation between the two devices. The predictor equation developed from the linear model was:

$$Estimated\ CSU\ Dustometer\ Concentration\ \left(\frac{g}{mi}\right) = -0.3324 + 1.4285 * EPAM\ 5000\ Concentration\ \left(\frac{mg}{m^3}\right) \quad \textbf{Equation 1}$$

Figure 5.2 shows the collected data points, along with the linear model.

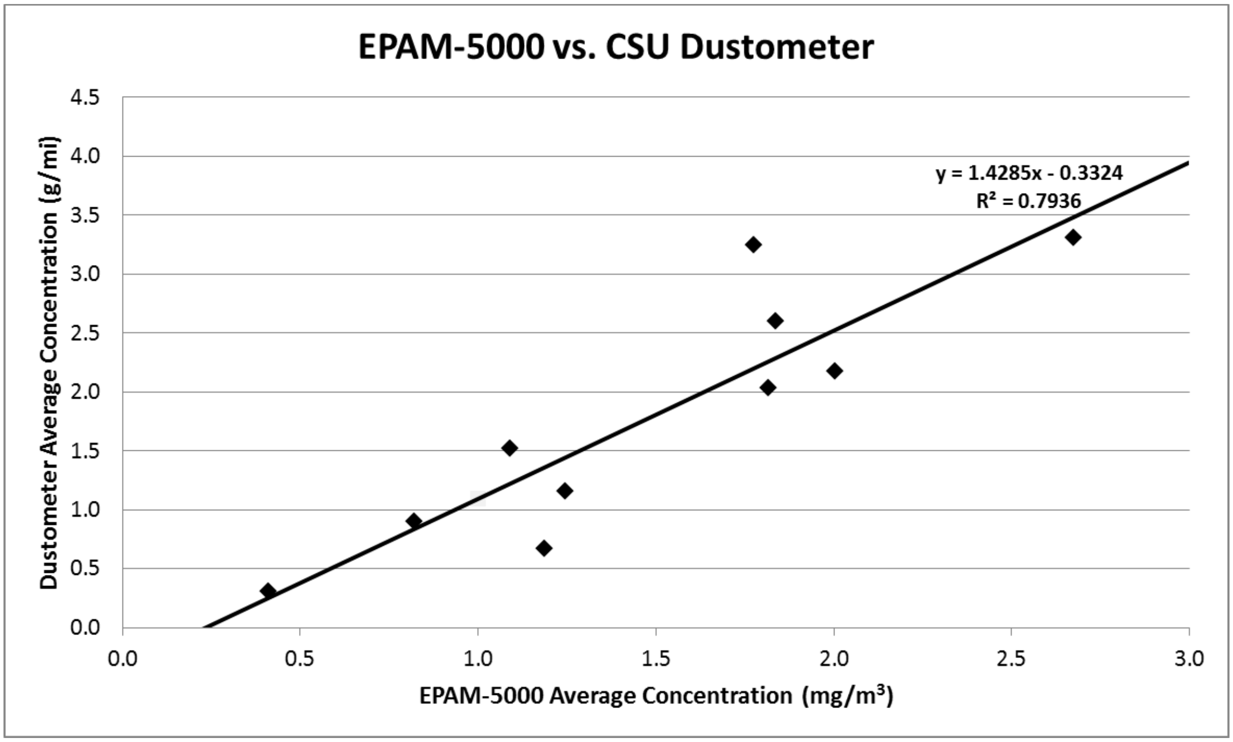

Figure 5.15 Plotted correlation data with linear model

Conducting data analysis in "R" also involved determining if any other roadway characteristics contributed to the correlation. Table 5.3 shows the data collected for each road, along with an explanation of each variable.

Table 5.9 Correlation Study Variables

Correlation Data						
Road	**EPAM**	**Dustometer**	**Moisture**	**Wind**	**Passing200**	**Temp**
Construction Rd.	2.674	3.31	1.74	0.4	6.5	72.3
Brubaker	1.188	0.67	1.03	3.7	12.5	80.3
Hornsby	1.246	1.15	0.71	2.6	15.1	83.0
Reservoir	2.003	2.17	2.40	2.0	21.3	72.0
Curtis	1.817	2.03	0.74	11.8	23.1	69.4
Welsh	1.775	3.25	0.66	3.2	11.0	76.7
Mason	0.820	0.90	2.16	5.3	13.9	75.7
Brubaker (2)	0.411	0.31	0.53	4.7	12.5	77.3
SandCreek1	1.092	1.52	0.90	7.1	10.8	81.3
CR - 51	1.838	2.60	0.52	2.9	14.3	80.7
Explanation of Data						
EPAM:	Average concentration of dust from EPAM-5000 using threshold method (mg/m3)					
Dustometer:	Average concentration of dust from CSU dustometer (g/mi)					
Moisture:	Average moisture percentage of road aggregate (%)					
Wind:	Average wind speed during data collection (mph)					
Passing200:	Percent of total aggregate passing #200 (75 μm) sieve (%)					
Temp:	Average temperature during data collection					

A model was developed with the Dustometer as the response, and all the other variables listed in Table 5.3 as predictors. Using the “R” step() function, the model was evaluated to determine what predictors resulted in the best fit model. The step function determined that the best fit model had only the EPAM as a predictor. This indicated that none of the other variables had a statistically significant effect on the correlation of the two devices.

5.5 Results and Recommendations

Based on the data analysis, it was concluded the CSU Dustometer is not reliable when testing roads treated with a dust suppressant. The Dustometer device will pick up large particles that are not actually dust being released into the air. This results in a false high value for dust concentrations after a road is treated. It was found that even with a finer screen on the filter box the results are still similar. Therefore, it is recommended that the Dustometer be used to find relative dust concentrations between untreated roads, but should not be used in determining the effectiveness of a suppressant based on testing before and after treatment is performed.

Also from the analysis, it was concluded that using the #38 screen on the Dustometer filter box resulted in a strong correlation between the Dustometer and the EPAM-5000. It is recommended that the #38 screen be used on the Dustometer to correlate the two devices on untreated roads.

5.6 Chapter Summary

This chapter described a study done to determine if a correlation exists between the EPAM-5000 dust monitoring device and the CSU Dustometer. The chapter discusses the two collection devices and how they are different. This is followed by a description of the data collection performed then a section describing the data analysis and results. The final section describes conclusions and recommendations based on the data analysis.

6. PHASE 3: CMAQ PROGRAM EFFECTIVENESS STUDY

6.1 Data Collection

6.1.1 Introduction

A key feature in assessing the effectiveness of the CMAQ program is data collection. The objective of data collection is to examine as many variables as possible that contribute to dust generation and dust suppression. Data collection was performed on each selected road both before and after it was treated with a suppressant. This chapter describes the methods of data collection utilized in determining the effectiveness of different suppressants. By using different methods of data collection, the most effective methodology could be established for different situations.

6.1.2 Background

In order to determine the effectiveness of a suppressant, the variables that impact said effectiveness must be considered. The literature review in Chapter 2 helped determine what factors to consider during the data collection process. The literature review suggested specific factors contributing to the dust suppression process regardless of climate or road conditions. These factors include soil parameters, weather conditions, dust concentrations, traffic conditions, suppressant type, and application rate.

Data collection included the use of stationary equipment such as traffic counters and air sampling equipment, as well as mobile equipment such as the CSU Dustometer. The idea behind this was not only to evaluate the effectiveness of the dust suppressants, but also to evaluate the effectiveness of the data collection itself and what methods work best in different situations.

By establishing an effective and accurate data collection process, counties can continue the research after this study ends. This will help develop a long-term model for ranking what projects will be the most cost effective, as well as help justify treatment to the public. By establishing an accurate model from historical data, counties will be able to use CMAQ funds and dust suppressants as efficiently as possible.

6.1.3 Study Sections

Test sections for data collection were selected from seven counties around Wyoming. See Figure 6.1. A total of 21 roads treated using CMAQ funds were tested during the data collection process.

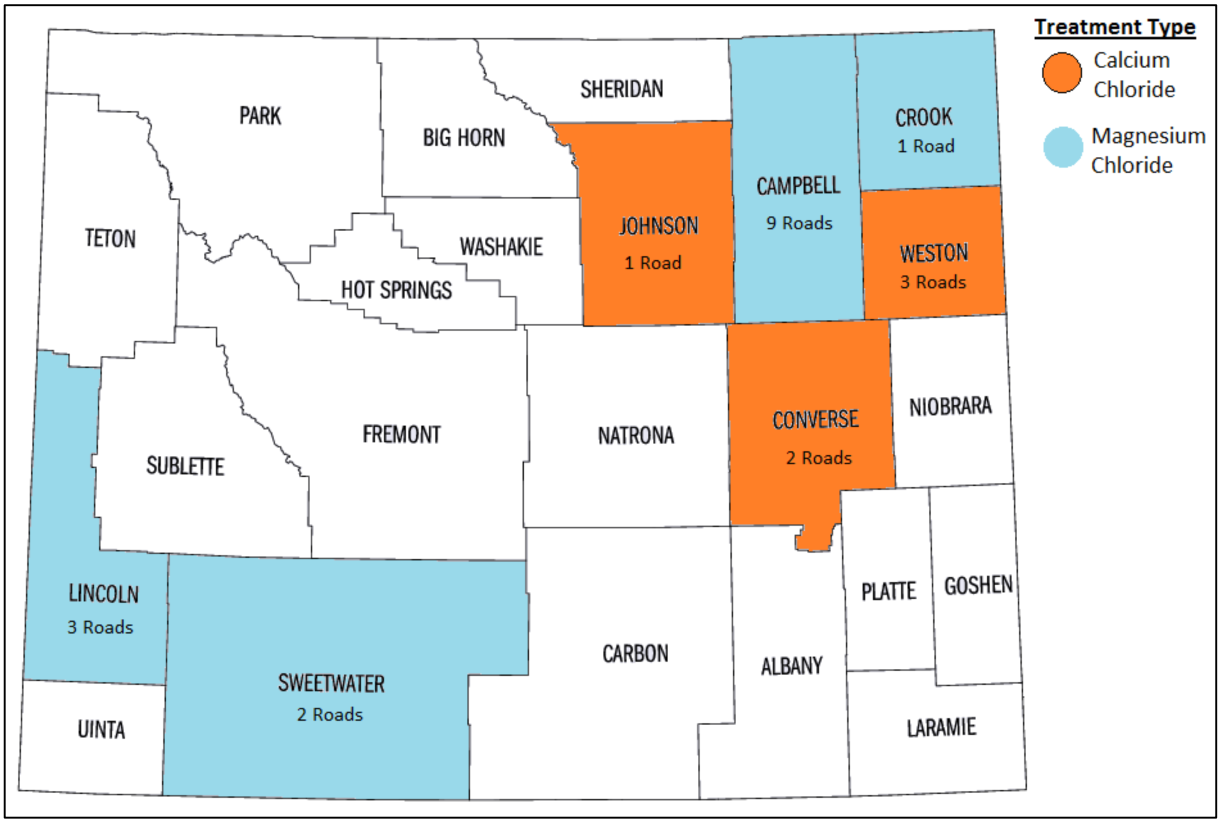

Figure 6.16 Counties selected for data collection

Currently, two types of dust suppressants are used in Wyoming with CMAQ funds. These are calcium chloride and magnesium chloride. Generally, each county uses the same type of suppressant for all CMAQ projects. The counties were selected based on their use of CMAQ funds, type of dust suppressant used, and annual average precipitation in the county. The goal in selecting roads for data collection was to perform testing on roads with different characteristics, so a determination of the cost effectiveness of CMAQ funds in different situations could be found. Table 6.1 provides a list of all roads tested for this study.

Table 6.10 List of Roads Tested

County	Road Name	Road Number	Year Tested
Campbell	Cosner	17-25	2014
	Clarkelen	17-22	2014
	Moore	17-78	2014
	Turnercrest	17-100	2015
	Todd	17-97	2015
	Christensen	17-21	2015
	Hayden	17-48	2015
	Black & Yellow	17-14	2015
	Iberlin	17-56	2015
Converse	Jenne Trail	13-34	2014
	Ross Road	13-31	2015
Crook	D-Road	18-68	2014
Johnson	TTT Road	16-51	2015
Lincoln	Muddy Creek	-	2014
	Gomer	12-338	2015
	Sublett-Pomeroy Basin	12-306	2015
Sweetwater	Wamsutter S	4-23	2015
	Patrick Draw	4-24	2015
Weston	Grieves	21-5	2015
	Bruce	21-7c	2015
	Mush Creek	21-58	2015

6.1.4 Data Organization

In order to organize the data collection process, a methodology was developed for classifying and tagging the various types of data. This included a classification code, so that exactly what each data type contained could be easily read and understood. In addition to the classification code, a data collection form was developed. A form was completed for each data collection period. This allowed the information collected to be easily accessed at a later date.

The data collection form included the traffic counter, moisture sample, aggregate sample, EPAM-5000 Haz-Dust Unit, Dustometer, wind, and temperature. These were determined to be the most important contributing factors to dust suppressant effectiveness based on the literature review.

For the traffic counter, the counter number and the data name used in the counter was noted on the form. Each moisture sample was tagged with a label indicating the classification code. For the aggregate sample, the bag of aggregate was tagged with the classification code. For the Haz-Dust unit, the internal tag number from the box was noted for the roadway. For the Dustometer, each Ziploc bag containing a filter was tagged with a classification number. For the wind and temperature readings, no classification code was used, and the readings were recorded directly onto the data collection form. Figure 6.2 shows an example data collection form.

Data Type	CMAQ Study Data Collection Form				
-	General Info	County:			
		Date:			
		Road Name:			
		Road Number:			
		Starting Mile Post:			
		Ending Mile Post:			
A	Traffic Counter	Counter #			
		Data Name (in counter)			
		Classification Code			
B	Moisture Sample	Sample #1 Label			
		Sample #2 Label			
		Sample #3 Label			
C	Aggregate Sample	Bag #1 Label			
D	Haz-Dust Unit	Box # & Location			
		Tag #			
		Box # & Location			
		Tag #			
E	Dust-o-Meter	Pass #1 (#38)			
		Pass #2 (#38)			
		Pass #3 (#38)			
		Pass #1 (#200)			
		Pass #2 (#200)			
		Pass #3 (#200)			
-	Wind Guage	Wind Speed Reading	Wind Speed	Direction	Temp
		Wind Speed Reading 1			
		Wind Speed Reading 2			
		Wind Speed Reading 3			
		Wind Speed Reading 4			
		Wind Speed Reading 5			

Figure 6.17 Example data collection form

6.1.5 Soil Samples

6.1.5.1 Aggregate Samples

An aggregate sample was collected for each road tested. The sample was made up of aggregate collected from three different sites in close proximity to where the rest of the data collection was taking place. The three sites to collect the soil sample were chosen from an area considered representative of the overall aggregate composition of the road section. The aggregate collected from the three sites were combined in a canvas bag and tagged with the appropriate classification code.

After a dust suppressant treatment is applied, the road aggregate is well sealed and can have characteristics similar to asphalt. Since it is difficult to obtain an aggregate sample from a treated road, samples were only collected before a road was treated. It was decided that samples would not be collected after treatment in order to avoid compromising the integrity of the treated sections.

6.1.5.2 Moisture Samples

The literature review indicated that the moisture content of the soil is an important aspect of dust generation on unpaved roads. In order to determine the water content, moisture samples were taken during data collection. For each road, a total of three moisture samples were taken before treatment, and an additional three samples were taken after treatment. Figure 6.3 shows the moisture tins used to collect samples.

Figure 6.18 Moisture tins

For the data collection that took place before a road was treated, one moisture tin was filled with soil from each of the three dig sites used to obtain the aggregate sample. With one tin from each of the three dig sites, this resulted in three moisture samples being collected for each road before a dust suppressant was applied. When obtaining a sample in the moisture tin, large rocks and debris were filtered out in order to obtain accurate moisture contents.

For data collection after a road was treated, one moisture tin was filled with soil from three equally spaced locations along the road. With one tin from each of these three locations, a total of three moisture samples were collected for each road after a dust suppressant was applied.

Moisture samples were collected from each road both before and after dust treatment in order to achieve several objectives. The moisture content obtained before treatment can be used to determine what role it plays in dust concentrations. The chloride suppressants used in this study are designed to increase moisture content. Determining moisture content after treatment can help identify if a suppressant is performing as intended.

6.1.6 Weather Conditions

The weather data collected for this study included wind and temperature readings. Wind readings were used to determine if higher winds resulted in more dust being generated from a road. Temperature readings were used to determine if higher temperatures contributed to more dust generation. Higher temperatures tend to dry out a road and make small particles more prone to being lifted from the road surface. Figure 6.4 shows the type of handheld meter used to determine wind speed and temperature.

Figure 6.19 Handheld wind meter and thermometer

In order to determine if wind was a factor in dust generation, a handheld wind gauge was used to find wind speed and direction readings throughout the data collection process. For each data collection period on each road (three hours), a minimum of three wind readings were taken with the gauge. The average of these three readings was used in determining if a correlation existed between wind speed and dust pollution.

In order to determine if temperature was a factor in dust generation, a handheld thermometer was used to find the ambient air temperature throughout the data collection process. For each data collection period on each road, a minimum of three temperature readings were taken with the thermometer. The average of these three readings was used to determine if a correlation existed between temperature and dust pollution.

6.1.7 Dust Concentrations

6.1.7.1 CSU Dustometer

In order to determine the effectiveness of different dust suppressants, a mobile dust monitoring system was used. The device chosen was the Colorado State University Dustometer. This device is attached behind a vehicle, making it mobile. The mobility of the device, as well as the short duration of each test, means that many data points can be recorded in one day. The on/off switch for the device is located next to the driver’s seat. This means the entire setup can be operated by one person.

The side of the filter box facing the rear wheel is covered with a mesh screen. This screen is intended to stop particles coarser than dust from entering the filter box and collecting on the filter. Two mesh screen sizes were used during data collection, (1) a #38 and (2) a #200. The two different sizes were used to determine if one size was preferable over the other in measuring dust concentrations on the road.

A Chevrolet Suburban was used to perform the dust measurements. The vehicle and Dustometer were operated at a speed of 40 mph. A one-mile test section was marked out before any measurements were taken. To perform a measurement, a pre-weighed filter paper was inserted into the filter box. The generator mounted on the cargo carrier was started and the device was readied for a data collection run. The vehicle was started and brought to a speed of 40 mph. At the start of the one-mile section, the suction pump was turned on. At the end of the one-mile section, the suction pump was turned off and the vehicle was brought to a stop. The pre-weighed filter, which had collected dust throughout the measurement, was carefully inserted into a sealed bag to be re-weighed at the laboratory.

For each test section, three replicate dust measurements were made with each of the two screen sizes (#38 and #200) on the filter box. These same measurements were repeated once the road was treated. The Suburban was driven in the same direction and wheel path to obtain three replicate measurements. The average of these three measurements was used to determine the concentration of dust on the road in grams per mile before and after treatment.

6.1.7.2 EPAM-5000

In order to assess the effectiveness of dust suppressants, a stationary dust monitoring device was also used. The device used for this study was the HAZ-DUST EPAM-5000 environmental particulate air monitor. This device is useful as it is portable and has a minimal number of parts. The unit requires only two parts to operate: (1) The actual unit itself and (2) a sampling inlet. The unit operates by drawing dust particles into a sensor head and detecting said particles once every second. Dust concentrations are instantaneously calculated and displayed on the unit's LCD. In addition, all data points are stored in the memory for later analysis.

In order to determine the PM_{10} pollution from a road, the EPAM-5000 was fitted with a 10μm inlet sleeve. The size selected in the device's system options was also set to PM_{10}. The sampling rate was set at 10s. This meant that every 10 seconds, an average ambient PM_{10} concentration data point was saved in the memory. The 10-second sampling rate was used to preserve memory and battery life on the unit while still acquiring frequent data points

To evaluate the concentration of dust released from a road, an EPAM-5000 was placed on each side of the road being tested. Each device was approximately one to two feet from the edge of the traveled way. To begin a data collection period, the device was turned on and set to run. Once a data collection period was complete, the device was turned off. The device could then later be connected to a PC, and the data it collected could be downloaded.

Originally, each data collection period with the device was four hours long. However, after analyzing the data acquired from several roads, it was determined that a three-hour sampling time resulted in the same average dust concentrations for each road as that acquired with a four-hour sampling time. Once this was determined, the data collection period was reduced to three hours for each test section. Each section was tested using the EPAM-5000 both before and after being treated with a dust suppressant.

6.1.8 Traffic Counts

An important factor in dust generation on unpaved roads is vehicle characteristics. In order to evaluate dust suppressant effectiveness on a road, it was necessary to determine the vehicle composition, volume, and speed of the road. To achieve this, traffic counters were installed across the road during the data collection period. The counters used were Centurion pneumatic tube counters, which log data on vehicle speed, vehicle composition, and total volume.

Each data collection period was initially four hours. Once it was determined that the same data could be collected in a shorter time, the collection period was reduced to three hours. The traffic counter and the EPAM-5000 devices collected data simultaneously for a three-hour period on each untreated road. After the road had been treated, the measurements were repeated for another three-hour span.

6.1.9 Climate Conditions

It has been noted in numerous studies that climate has a large influence on dust pollution on unpaved roads. In order to assess the role precipitation plays in dust generation on unpaved roads in Wyoming, data were collected from counties with varying average annual precipitation. Local climate and precipitation were determined using historical data for each county. Table 6.2 shows the annual precipitation for the counties evaluated in this study.

Table 6.11 Climate Classification

County	Annual Precipitation (in.)			
	<10	10 - 14	14 - 18	> 18
Campbell			x	
Converse		x		
Crook				x
Johnson		x		
Lincoln			x	
Sweetwater	x			
Weston			x	
Wyoming Average: 12.9 in. Lowest: Big Horn County, 6.8 in. Highest: Teton County, 22.3 in.				

Counties were selected from different precipitation ranges. Crook County, which has a high annual precipitation, contrasts with areas such as Sweetwater County, which experiences the third lowest annual precipitation in Wyoming. Contrasting climates were evaluated to help provide data that could correlate climate with performance of a suppressant and the duration of its effect.

6.2 Data Analysis

The data collected from the 21 roads around Wyoming are analyzed in this chapter to determine the effectiveness of the dust treatments used with CMAQ funds. All 21 roads have data available before treatment, and eight roads have data available after treatment. Included in this chapter are cost comparisons between treatment types, dust concentrations before and after treatment, traffic and weather conditions, and analysis of soil samples collected from each road. Regression analysis on variables is conducted to determine correlations between dust concentrations and road characteristics. By comparing costs and treatment effectiveness, the overall effectiveness of CMAQ funds is determined. Appendix sections C through F contain the data analyzed in this section.

6.2.1 Cost and Application Rate

As part of the data analysis, calcium chloride ($CaCl_2$) and magnesium chloride ($MgCl_2$) are compared. For the 21 roads tested, six are treated with $CaCl_2$ and 15 with $MgCl_2$. The costs are calculated based on the cost of applying the chemical. Blading and watering costs can vary greatly depending on the road. Also, some roads tested do not require blading before being treated. Since these costs are so variable, they are not included in the analysis. Only the cost of the dust control product used and its application are included. Costs for application of the chemical provided by counties in dollars per mile are normalized by dividing cost per mile by the width of the road to get a cost per mile per foot ($/mile-foot). Normalizing cost of treatment by the width of the road provides a better comparison of costs between roads. The results are summarized in Table 6.3.

Table 6.12 Costs and Application Rate Summaries

Parameter		Minimum Value	Maximum Value	Average	Standard Deviation
Treatment cost/mile	$CaCl_2$	$4,675	$6,187	$5,563	$463
	$MgCl_2$	$2,700	$6,266	$5,202	$957
	Total	$2,700	$6,266	$5,305	$894
Treatment cost/mile-ft	$CaCl_2$	$157.3	$225.0	$197.9	$25.7
	$MgCl_2$	$136.0	$224.8	$193.5	$25.6
	Total	$136.0	$225.0	$194.7	$25.7
Application Rate (GSY)	$CaCl_2$	0.40	0.50	0.46	0.04
	$MgCl_2$	0.47	0.50	0.50	0.01
	Total	0.40	0.50	0.48	0.03

Table 6.3 shows that based on treatment cost per mile, there are large differences in application costs, with a standard deviation of almost $1,000 dollars for $MgCl_2$. However, this measure of cost does not take the width of the road into account. A wide road will require more dust control product per mile than a narrow road, resulting in a higher cost. By normalizing the cost based on road width, a clearer comparison can be established. It can be seen that when costs are normalized by road width, the standard deviation decreases significantly. This observation indicates that cost per mile-foot is a better way of determining cost of treatment.

The analysis indicates that $MgCl_2$ seems to be slightly cheaper on average in terms of cost/mile-foot. The standard deviation of costs for both chemicals is nearly identical. The standard deviation of cost/mile-foot for all roads is $26, showing that costs seem to be standard across the state with no large deviations in the prices counties are paying for treatment chemicals. This indicates that counties are using similar methods for treatment. It also indicates that none of the counties in this study are spending significantly more money per road.

$CaCl_2$ also seems to have a lower application rate on average. This is expected as the literature review suggests the use of $CaCl_2$ requires a lower concentration than $MgCl_2$. The overall average and standard deviation for application rate also shows that a value between 0.4 and 0.5 gsy seems to be standard for Wyoming. This indicates some uniformity in the application techniques counties are using for treating their roads. The values also fall within the range of between 0.18 and 0.55 gsy suggested in the literature for chloride salts.

6.2.2 Traffic and Weather Characteristics

As part of the analysis, data from the traffic counters are used to determine average daily traffic (ADT), percent of traffic comprised of trucks, and 85th percentile speed. ADTs were calculated by the Centurion CC software based on the three- or four-hour traffic counts conducted during data collection. In situ weather conditions, including wind speed and temperature, are also included. The results from the collected data are shown in Table 6.4.

Table 6.13 Traffic and Weather Data Summaries

Parameter	Minimum Value	Maximum Value	Average	Standard Deviation
Average Daily Traffic (ADT)	80	834	306	215
Percent Trucks	0%	71%	25%	19%
85th Percentile Speed (mph)	25.7	62.1	42.3	7.2
Wind Speed Before Treatment (mph)	1.0	18.2	6.2	3.7
Wind Speed After Treatment (mph)	1.6	8.9	5.2	2.7
Temp Before Treatment (F)	63.7	91.4	75.9	7.0
Temp After Treatment (F)	63.0	86.7	76.2	7.0

The results from the weather readings indicate that average wind speeds before and after treatment are similar. Additionally, temperatures are similar before and after treatment and have the same standard deviation. The results of the weather data show that significant weather changes do not seem to be a factor before and after treatment. The collected weather data can be used in future statistical analysis to determine if they contribute to dust concentrations, and dust palliative effectiveness.

The average 85th percentile speed was just over 40 mph with a standard deviation of 7 mph. The posted speed limit on many unpaved roads in Wyoming is 40 mph. This indicates that most drivers are obeying posted speeds. The maximum value of 62 mph shows there are some roads that might have a problem with vehicles traveling too fast. Further analysis of speeds would help determine if speed control measures are needed on certain roads to reduce dust emissions.

Many roads also have a high percentage of trucks, with the highest being 75% truck traffic. This is an indication of the oil and gas impact on CMAQ roads. Many of the roads also have a high ADT, which indicates that roads are being selected for treatment based on traffic volumes. It is also an indication that these unpaved roads experience high vehicle volumes due to oil and gas industry vehicles. The average for all roads was 306 vehicles/day. This value falls within the range of 15 to 500 vehicles per day that the literature review suggests as appropriate for treatment with a dust suppressant (Edvarsson, 2009). Figure 6.5 shows the ADT for all roads, along with the threshold values.

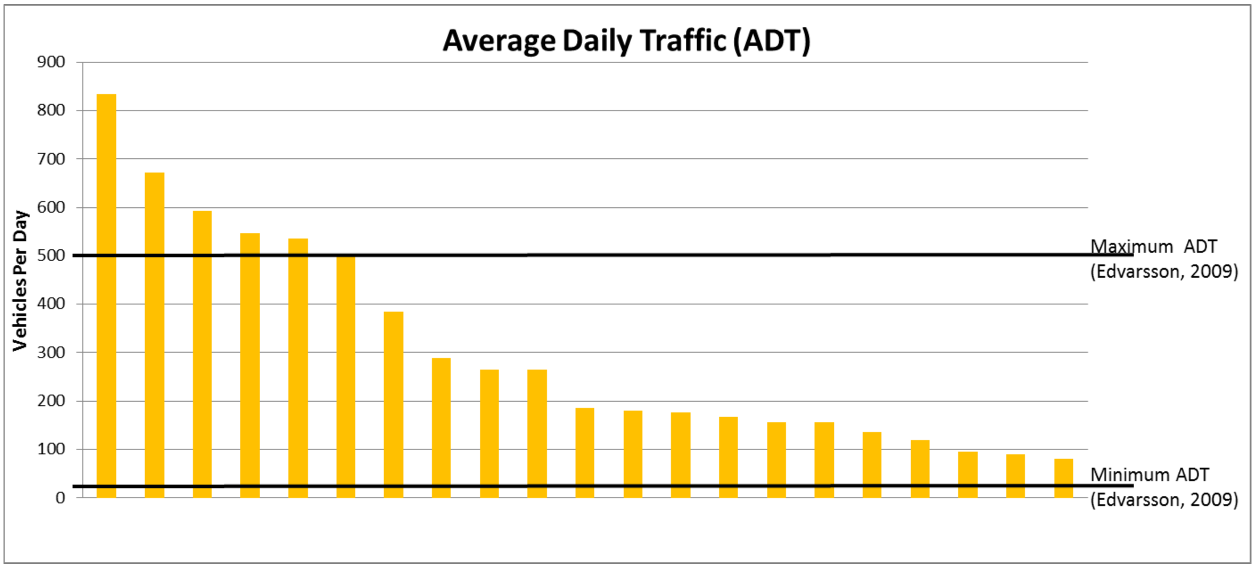

Figure 6.20 ADT for roads tested

As seen in Figure 6.5, 16 of the roads tested had ADT values within the acceptable range for treatment. Five roads were above the recommended ADT threshold. It is expected that roads above the threshold will experience a quicker deterioration of dust treatment benefits. However, the five roads above the threshold value are used for oil and gas activities. The nature of the oil and gas industry means that roads will have large fluctuations in vehicle volume depending on outside variables. Permanent dust control, such as paving the roads, might not be warranted if the ADT values fall below the 500 vehicles per day threshold during certain periods of the year.

6.2.3 Soil Analysis

The soil and moisture samples were analyzed in the lab in accordance with AASTHO standards to determine soil conditions. Sieve analysis was performed in accordance with AASHTO T 11 and T 27 to determine the gradation of the soil. Atterberg limit tests were performed using AASHTO T 89 and T 90 to determine the liquid limit, plastic limit, and plastic index of the soil. Moisture contents were calculated in accordance with AASHTO T 265. Table 6.5 shows the summary of the soil analysis, and Wyoming Department of Transportation specifications (WYDOT, 2010) for unpaved roads are also shown where applicable.

Table 6.14 Soil Data Summaries

Soil Conditions					
Parameter	Minimum Value	Maximum Value	Average	Standard Deviation	WYDOT Specifications
Liquid Limit (LL)	13.20	25.97	17.23	3.12	0 to 30
Plastic Limit (PL)	0.00	20.00	6.91	6.98	-
Plasticity Index (PI)	3.42	21.50	10.32	5.87	4 to 12
Passing #200 Sieve	5.1%	19.4%	10.9%	3.2%	4 to 15
Moisture Content Before Treatment	0.3%	6.1%	2.1%	1.3%	-
Moisture Content After Treatment	1.5%	7.2%	3.0%	2.0%	-

Analysis indicates that the average value for liquid limit falls within the WYDOT specification for unpaved roads. The plasticity index is also within the specification range. This shows that the unpaved roads included in the study had clay content within the acceptable range. Soils with some clay will generally perform better than granular soils when a dust suppressant is applied. This suggests that suppressants will perform effectively on these roads.

The standard deviation for percentage passing the #200 sieve (fines) is 3.2%, indicating that the unpaved roads' soil compositions are consistent in the amount of fines. The average percentage of fines is within the WYDOT specifications for unpaved roads. While within the limits, the average percent fines are on the higher end of the acceptable range. This can be expected as roads chosen for treatment are usually dustier, and this can partially be caused to a higher percentage of fine material in the soil. The literature review suggested that the optimum percentage of fine material for unpaved roads requiring dust treatment is between 5% and 30%. All 21 roads had values within this range, indicating that dust treatments are being applied to roads with good characteristics for dust treatment.

Analysis of the moisture content data shows that the soils have relatively low moisture contents, with the average being 2.1%. This low moisture content is due to the hot, arid climate of Wyoming. The data also indicate that the soils have higher average moisture contents after treatment with a dust control product. This is due to chloride-based dust suppressants being water absorbent. The higher moisture levels after treatment show that the suppressants are working as intended by keeping the surface soil of the roads damp.

The results of the soil gradation analysis and Atterberg limit tests (LL, PI) were used to classify the soil type for each road. Soil classification was performed in accordance with the AASHTO Soil Classification System. Table 6.6 shows the soil classifications.

Table 6.15 AASHTO Soil Classification

AASHTO Soil Classification		
Classification Group	**# of Roads**	**Type of Material**
A-1-a	4	stone fragments, gravel and sand
A-1-b	4	
A-2-4	3	silty or clayey gravel and sand
A-2-6	10	

As seen in Table 6.6, the soils fell into four classification groups. The most common group was A-2-6. According to the AASHTO System, all four of these groups have a general rating of "excellent to good" as a subgrade material. Eight roads consisted of soil material composed mainly of stone fragments, gravel and sand. Thirteen roads consisted of soil material composed mainly of clayey gravel and sand. The results of the soil classification indicate there is uniformity in the aggregate materials used in the unpaved roads treated with CMAQ funds.

6.2.4 Dust Suppressant Effectiveness

The average dust concentration from the EPAM-5000 is calculated by using the threshold method described in Chapter 3. A threshold of 0.5 mg/m^3 was used for untreated roads, and 0.01 mg/m^3 was used for treated roads. The threshold was lowered for treated roads due to the very low dust concentrations recorded. The average from the Dustometer is calculated by taking the average of the three data points collected on each road.

At the time of analysis, data for dust concentrations before treatment from the EPAM-5000 are available for all 21 roads, and data for dust concentrations before treatment from the CSU Dustometer are available for 18 roads. Data for dust concentrations after treatment from the EPAM-5000 are available for eight roads, and data for dust concentrations after treatment from the CSU Dustometer are available for five roads. Data collected from roads after treatment was conducted one to two weeks after the treatment had taken place, as the literature review suggested this is when dust suppressants reach their peak effectiveness. The data collection results are summarized in Table 6.7.

Table 6.16 Dust Concentrations

Parameter		Minimum Value	Maximum Value	Average	Standard Deviation
EPAM-5000 Dustbox Concentration (mg/m^3)	Before Treatment (21 Roads)	0.914	4.036	1.938	0.796
	After Treatment (8 Roads)	0.020	0.141	0.044	0.040
CSU Dustometer Concentration (g/mi)	Before Treatment (18 Roads)	0.67	3.98	1.87	0.982
	After Treatment (5 Roads)	0.02	0.82	0.45	0.315

The dust concentrations from the EPAM-5000 before and after treatment show that the dust suppression efforts are working very well with an average reduction in dust of 1.894 mg/m^3. Dust concentrations after treatment were available for eight roads, and all eight were very low values close to zero with a low standard deviation. This indicated that the treatment is effective and the roads not yet tested after treatment should have similar values. From the data, it can be concluded that the CMAQ treatments reduce dust concentrations on roads to nearly zero in the short term. Collecting more data on roads several months after treatment will give an indication of the long-term effectiveness of different applications.

As noted previously, the CSU Dustometer is not as effective at evaluating dust concentrations before and after treatment. The standard deviation shows there is a high degree of variance in data collected with the Dustometer, even for treated roads. This contradicts the consistently low values found with the EPAM device. A paired t-test is used to determine if the concentrations before and after treatment with the Dustometer were statistically different. The five roads that have data available before and after treatment are used for the test. Table 6.9 shows the results of the data obtained.

Table 6.17 CSU Dustometer Values

CSU Dustometer Concentration			
County	**Road**	**Before Treatment (g/mi)**	**After Treatment (g/mi)**
Lincoln	Muddy Creek	2.45	0.65
	Gomer	1.37	0.26
	Sublett-Pomeroy Basin	1.60	0.50
Converse	Jenne Trail	1.80	0.82
Campbell	Cosner	3.98	0.02

Table 6.18 T-Test for CSU Dustometer Values

t-Test: Paired Two Sample for Means		
	Before Treatment	*After Treatment*
Mean	2.238	0.450
Variance	1.105	0.099
Observations	5	5
Pearson Correlation	-0.56	
Hypothesized Mean Difference	0	
df	4	
t Stat	3.19	
P(T<=t) one-tail	0.02	
t Critical one-tail	2.13	

Based on the t-test, it can be seen that the t value is greater than the t critical value, indicating there is a statistical difference between the values at a 95% confidence level. This indicates that dust concentrations collected with the device are consistently lower after treatment. The values from the collected data indicate that the treatments are effective, with an average reduction in dust of 1.42 grams/mile.

6.2.5 Regression Analysis

The factors that can contribute to dust generation were evaluated during collection of field data. These factors were determined through literature on the topic of dust concentrations on unpaved roads. Each dust collection device was used as the response, and all the variables were used as predictors for untreated roads. This was done to determine if a regression model relating the dust collection devices to the variables could be developed. The EPAM-5000 and the CSU Dustometer were each analyzed individually against the predictors.

The Akaike information criterion (AIC) measures the quality of a statistical model for a given dataset. It can be used in model selection to determine what the best fitting model will be (Kutner et al., 2004). The criteria are based on likelihood for that model and have a penalty for adding terms to the model. The Bayesian information criterion (BIC) is a modified version of the AIC that also determines what the best fit model will be for a given dataset. The BIC assigns a larger penalty term for the addition of parameter than the AIC model does (Schwarz, 1978). The analysis conducted for this study utilized stepwise functions using both AIC and BIC to predict the best fitting model.

6.2.5.1 EPAM-5000

The data collected in the field were combined into a comprehensive table to be used for statistical analysis. See Table 6.10. The objective of this analysis was to develop a regression model relating dust concentrations from the EPAM to roadway characteristics. Since dust concentrations on the roads are generally very low after being treated with a dust suppressant, only data collected on untreated roads were used. To develop a model, data from 21 roads were used.

Table 6.19 EPAM Dataset

Road	Average EPAM Concentration (mg/m^3)	Percent Fines (%)	Liquid Limit	Plasticity Index	Moisture Content (%)	Trucks	ADT	Average Speed (mph)
1	2.227	19.4	18.8	3.4	1.62	13.0	95	35.2
2	0.973	12.5	15.8	15.8	2.83	0.0	80	40.5
3	0.927	8.9	16.6	4.5	1.41	7.0	120	38.8
4	2.674	14.1	18.0	4.6	4.01	45.0	536	43.5
5	0.914	10.8	17.0	3.7	2.07	37.0	592	38.2
6	1.779	14.5	26.0	6.0	2.25	16.0	384	62.1
7	1.846	11.6	17.6	17.6	2.10	42.4	834	54.7
8	1.433	5.1	15.1	15.1	0.28	62.5	672	47.8
9	3.043	10.2	21.5	21.5	0.41	71.4	168	37.3
10	2.017	8.1	13.2	13.2	1.49	13.0	288	43.6
11	1.287	11.3	16.7	4.8	1.27	33.0	186	43.0
12	3.010	10.5	19.5	19.5	2.91	34.0	264	46.9
13	1.870	5.9	15.9	15.9	1.12	12.0	136	42.3
14	1.471	11.1	14.1	14.1	1.91	37.0	504	42.9
15	4.036	9.6	16.2	5.1	2.35	16.0	264	40.6
16	2.166	8.3	15.6	15.6	0.99	24.0	156	34.4
17	1.330	10.5	16.7	4.8	3.18	21.0	546	45.5
18	1.673	13.4	23.5	5.9	6.12	19.0	176	38.0
19	2.383	8.1	13.3	13.3	0.44	20.0	156	45.7
20	1.270	11.0	15.7	6.3	0.70	7.0	90	41.8
21	2.371	14.9	15.0	5.9	0.53	0.0	180	25.7

The findings from the data collection seen in Table 6.10 were evaluated in the statistical analysis software "R" to determine if a regression model existed between the EPAM dust concentrations and the road characteristics. To achieve this, R was used to fit a linear model to the set of data points with the EPAM dust concentration as the response and the road characteristics as the predictors. The R step() function was used to find the best model based on AIC. This function found no evidence of a linear relation between the response (EPAM) and any of the independent predictors.

The standardized residuals were analyzed, and it was determined that road number 15 had a higher residual value than the other roads. This can be seen in Table 6.10, as road 15 has a significantly higher EPAM dust concentration than the other roads. This data point was considered an outlier and dropped from the dataset. Further examination of the standardized residuals indicated that a second outlier, road 2, was present in the dataset. This data point was also dropped. Once the second outlier was removed, the stepwise function using AIC found evidence that the variables, percent fines, PI, and ADT, were related to the response. There was also evidence noted of interaction between the PI and ADT, which showed that ADT had less of an effect on the response with higher PI values. The stepwise function using BIC found evidence that the variables, percent fines and PI, were related to the response. Table 6.11 shows the best fit models using AIC and BIC.

Table 6.20 EPAM Best fit Models

EPAM Linear Model, 2 Outliers Removed				
Model	**Predictor**	**Coefficient**	**R-squared**	**p-value**
Best AIC Model	Intercept	-0.194	0.6292	0.001561
	Fines	0.122		
	PI	0.093		
	ADT	-0.001		
Best BIC Model	Intercept	-0.423	0.5717	0.001132
	Fines	0.125		
	PI	0.091		

The only difference between the two models was the addition of the ADT term in the AIC model. The AIC model had a slightly higher R-square value, giving evidence that it could be the better fit. The negative coefficient for ADT seems irregular, as it would be expected that dust concentrations from the EPAM would increase with a higher daily traffic. However, the ADT coefficient is very small. The equation developed from the AIC model was:

$$\boldsymbol{Estimated\ EPAM\ 5000\ Concentration}\ (\boldsymbol{mg/m\text{^}3}) = \boldsymbol{-0.194} + (\boldsymbol{0.122} * \boldsymbol{Percent\ Fines}) + (\boldsymbol{0.093} * \boldsymbol{PI}) - (\boldsymbol{0.001} * \boldsymbol{ADT}) \quad \text{Equation 2}$$

The equation developed from the BIC model was:

$$\boldsymbol{Estimated\ EPAM\ 5000\ Concentration}\ (\boldsymbol{mg/m\text{^}3}) = \boldsymbol{-0.0423} + (\boldsymbol{0.125} * \boldsymbol{Percent\ Fines}) + (\boldsymbol{0.091} * \boldsymbol{PI}) \quad \text{Equation 3}$$

Both of the models selected percent fines and PI as predictors, and both models had similar coefficients for these predictors. The AIC and BIC models agree for the most part, with the only difference being the AIC model included ADT as a predictor. Whereas BIC picks a more parsimonious model by dropping ADT

Since there were only 21 data points to start with, each outlier can create substantial noise in the data, making it difficult to find relationships between the predictors and the response. Removing the outliers resulted in a statistical model with a relatively high R-square value. In the future, taking multiple readings on each road with the EPAM could help to reduce noise in the data.

Inspection of the characteristics of the outliers did not indicate any substantial differences compared with other data points in the list. Apart from recording high concentrations with the EPAM, all other variables fell within the normal range. Future analysis of other roadway variables may indicate why these data points are outliers.

6.2.5.2 CSU Dustometer

The data collected in the field were combined into a comprehensive table to be used for statistical analysis (See Table 6.12). The objective of this analysis was to develop a regression model relating dust concentrations from the Dustometer to roadway characteristics. Since dust concentrations on the roads are generally very low after being treated with a dust suppressant, only data collected on untreated roads were used. To develop a model, the Dustometer and road data available for 18 roads were used.

Table 6.21 Dustometer Dataset

Road	Dustometer Concentration (g/mi)	Percent Fines (%)	Liquid Limit	Plasticity Index	Moisture Content (%)	Trucks	ADT	Average Speed (mph)
1	2.5	19.4	18.8	3.4	1.62	13.0	95	35.2
2	1.4	12.5	15.8	15.8	2.83	0.0	80	40.5
3	1.6	8.9	16.6	4.5	1.41	7.0	120	38.8
4	1.8	14.1	18.0	4.6	4.01	45.0	536	43.5
5	0.7	10.8	17.0	3.7	2.07	37.0	592	38.2
6	4.0	11.6	17.6	17.6	2.10	42.4	834	54.7
7	0.9	8.1	13.2	13.2	1.49	13.0	288	43.6
8	0.8	11.3	16.7	4.8	1.27	33.0	186	43.0
9	1.7	10.5	19.5	19.5	2.91	34.0	264	46.9
10	2.2	5.9	15.9	15.9	1.12	12.0	136	42.3
11	1.0	11.1	14.1	14.1	1.91	37.0	504	42.9
12	0.8	9.6	16.22	5.11	2.35	16.0	264	40.6
13	1.6	8.3	15.6	15.6	0.99	24.0	156	34.4
14	4.0	10.5	16.7	4.8	3.18	21.0	546	45.5
15	1.4	13.4	23.5	5.9	6.12	19.0	176	38.0
16	2.4	8.1	13.3	13.3	0.44	20.0	156	45.7
17	2.5	11.0	15.7	6.3	0.70	7.0	90	41.8
18	2.5	14.9	15.0	5.9	0.53	0.0	180	25.7

The findings from the data collection seen in Table 6.12 were evaluated in the statistical analysis software "R" to determine a suitable regression model between the Dustometer dust concentrations and the road characteristics. To achieve this, R was used to fit a linear model to the set of data points with the Dustometer dust concentration as the response and the road characteristics as the predictors. The R step() function was used to find the best model based on AIC as well as BIC

The standardized residuals were analyzed, and it was determined that road number 14 had a higher residual value than the other roads. This can be seen in Table 6.12, as road 14 has a high Dustometer concentration compared with the other roads. This data point was considered an outlier and dropped from the dataset. Further examination indicated that the predictor LL had collinearity with the moisture content predictor. This collinearity was affecting the results of the stepwise function, so LL was removed from the model. The stepwise function using AIC found evidence that the variables, percent fines, moisture content and vehicle speed, were related to the response. The stepwise function using BIC found the same variables were related. Since the AIC and BIC models agreed, only one equation was found for the Dustometer. Table 6.11 shows the best fit models using AIC and BIC.

Table 6.22 Dustometer Best fit Models

Dustometer Linear Model, 1 Outlier Removed				
Model	**Predictor**	**Coefficient**	**R-squared**	**p-value**
Best AIC and BIC Model	Intercept	-1.938	0.3122	0.1688
	Fines	0.139		
	Moisture	-0.264		
	Speed	0.065		

The agreement between the AIC and BIC models indicated that the best fit model had the predictors shown in Table 6.13. The fines predictor also showed up in the EPAM equation, indicating it is a strong contributor to dust concentrations. However, the model has a relatively low R-square value, indicating that the data do not show a strong relation between the response and the predictors. The equation developed from the models was:

$$\boldsymbol{Estimated\ Dustometer\ Conc.}\left(\frac{\boldsymbol{mg}}{\boldsymbol{m^3}}\right) = -\mathbf{1.938} + (\mathbf{0.139} * \boldsymbol{Percent\ Fines}) - (\mathbf{0.264} * \boldsymbol{Moisture\ Content}) + (\mathbf{0.065} * \boldsymbol{Speed}) \qquad \text{Equation 4}$$

Since there were only 18 data points to start with, each outlier can create substantial noise in the data, making it difficult to find relationships between the predictors and the response. Removing the outlier resulted in a statistical model with a higher R-square value, and predictors that make sense with the findings of the EPAM regression analysis.

6.3 Chapter Summary

This chapter summarized the methods used for organizing data collected in the field. It followed with discussing techniques used for collecting different types of data. It also described methodologies for determining the most effective data collection methods. This included what equipment was the best in different situations. The methodologies developed will help in future testing of dust suppressant effectiveness on unpaved roads.

The data collection process involved evaluating all the major factors that contribute to dust suppressant effectiveness. These include soil parameters, weather conditions, dust concentrations, traffic counts, climate, and type of suppressant used. All of these factors would be used later during data analysis to establish a comprehensive matrix to evaluate the cost effectiveness in different situations. Data collection was performed on each road in the study both before and after the road was treated with a suppressant. Testing done before treatment established a baseline for the levels of dust that could be expected from a road if it remained untreated. Data collected after the road was treated could then be compared with the values obtained before treatment to determine the effectiveness of treatments.

This chapter provided analysis of data collected throughout the study. The treatment costs and application rates were analyzed. Effectiveness of treatments was determined by examining data collected with the EPAM and Dustometer devices. Traffic and weather conditions were examined to determine their effect on dust concentrations. The results of the soil analysis were compared with WYDOT standards for unpaved roads. The analysis of these variables indicated that treatment techniques appear to be relatively standard across the state for roads treated with CMAQ funds.

This chapter also described the statistical analysis conducted on the data. Regression analysis established relationships between the dust concentrations on unpaved roads and roadway characteristics. This analysis determined that due to the low number of data points currently available, it is necessary to remove outliers to establish accurate models. Once outliers were removed, statistically significant models were found.

7. CONCLUSIONS AND RECOMMENDATIONS

7.1 Summary

This study assessed the effectiveness of the CMAQ program in Wyoming. The evaluation was accomplished by utilizing field data and comprehensive statistical analysis to examine the effectiveness of various dust suppressants. This included monitoring dust suppressant application, surfacing aggregate type, traffic, weather, roadway performance, and fugitive dust emissions to provide a comprehensive assessment of the effectiveness of the dust suppression efforts paid for with CMAQ funds. Field data were collected on unpaved roads in Campbell, Converse, Crook, Johnson, Lincoln, Sweetwater and Weston Counties. Analysis of field data was used to provide recommendations on developing a statistical model for the most cost-effective use of future CMAQ funding. Due to the performance difference between unpaved roads in drier and wetter climates, the results from this study are most applicable to the interior western United States and other dry climates throughout the world. The methodologies developed during this study are applicable for assessing the effectiveness of any dust control efforts, regardless of differences in precipitation.

Methodologies for assessing dust control effectiveness were developed for use as this study is continued in the future. These included developing techniques for collecting data on dust concentrations and roadway characteristics from unpaved roads. Techniques for analyzing data from the dust collection equipment, as well as accurate practices for collecting data with the equipment, were established. Time optimization was performed to establish the most efficient methods for collecting data on unpaved roads. Benefits and limitations of each dust measuring device were discussed, which aided in determining what methods worked best in different situations. A correlation between the dust measuring devices was also established. This will help future research, as it provides a way to convert between the two devices.

7.2 Conclusions

The conclusions drawn throughout the various phases of the study are presented in this section.

7.2.1 Phase 1: Methodologies for use of the EPAM-5000

The conclusions drawn from analysis of data collected with the Haz-Dust EPAM-5000 monitoring device are as follows:

- The EPAM is a reliable dust measuring device that can be used to compare dust concentrations before and after a road has been treated with a dust control product.
- A three-hour data collection period should be used to obtain accurate results and optimize the data collection time.
- When calculating the average dust concentration, a threshold value should be set and all values above that threshold should be used to calculate an average.
- Data collection should be conducted using the following standards.
    - One device should be placed on each side of the road to ensure the maximum dust concentrations are being recorded.
    - If only one device is available, place it on the downwind side of the road.
    - The device should be placed within 1 – 2 feet of the edge of the traveled way.

7.2.2 Phase 2: Correlation of EPAM-5000 and CSU Dustometer

A correlation study was conducted to compare dust concentrations recorded with the CSU Dustometer and the HAZ-Dust EPAM-5000. The conclusions drawn from this study are as follows:

- There is a good correlation between dust readings obtained with the CSU Dustometer and the EPAM-5000 on untreated roads.
- The CSU Dustometer has a tendency to collect larger particles that are not actually particulate matter being released into the air when used on treated roads.
- Outside factors, such as road and weather characteristics, are not statistically significant in affecting the correlation between the two devices.

7.2.3 Phase 3: CMAQ Program Effectiveness Study

7.2.3.1 General Characteristics

The conclusions drawn from analysis of the data collected on CMAQ roads are as follows:

- Counties are using similar methods for treatment.
- On average, MgCl2 seems to be slightly cheaper than CaCl2.
- Many roads have a high percentage of trucks, indicating the impact of oil and gas activities on CMAQ roads.
- The average ADT for all roads falls within the range that the literature review suggests as appropriate for treatment with a dust suppressant.
- Average values for soil parameters are within the WYDOT specifications for unpaved roads.
    - Liquid limit
    - Plasticity index
    - Percent fines
- On average, road surfaces have higher moisture contents after treatment with chlorides, indicating that treatments are working as intended.

7.2.3.2 CMAQ Effectiveness

The Haz-Dust EPAM-5000 and the CSU Dustometer collected data on dust concentrations before and after treatment. The conclusions drawn from analysis of the data are as follows:

- Results from the devices show that the dust suppression efforts are working very well.
- Treatments are reducing dust concentrations on roads to nearly zero.
    - This indicates that the CMAQ funds are being used effectively.

7.2.3.3 Regression Analysis

The conclusions drawn from regression analysis of factors contributing to dust concentrations are as follows:

- It is necessary to find and eliminate the data points that are outliers to obtain meaningful statistical models

- Regression analysis found evidence that the EPAM dust concentration is related to three road characteristics:
    - Percent of fines in the soil
    - Plasticity index
    - Average daily traffic
- Regression analysis found evidence that the Dustometer dust concentration is related to three road characteristics:
    - Percent of fines in the soil
    - Moisture content of the soil
    - Vehicle speed

7.3 Recommendations

Recommendations offered in this section are intended to aid in future determinations of dust suppressant effectiveness. They are made after careful examination of the methodologies developed for collecting and analyzing data, the applicability of the data collected, and the ways in which the information provided can be used by counties in the future. Recommendations on what procedures are effective and what can be improved are provided to enhance the techniques currently in place and to optimize the use of CMAQ funds in Wyoming. The ultimate goal of this study is to develop practices to better understand dust control on unpaved roads.

It is recommended that the long-term effectiveness of dust suppressants be evaluated. This can be accomplished by collecting data periodically on CMAQ roads after a dust treatment has been applied. This will determine how dust suppressant effectiveness is impacted over time. A benefit of doing this will be an accurate cost-benefit analysis. Performance curves can be generated to calculate the rate of decline of suppressant effectiveness. This rate of decline can be compared with road characteristics to determine what factors play a part in decreasing suppressant effectiveness over time. Evaluating long-term impacts will also aid in developing a statistical model to rank which roads need treatment first. An accurate statistical model will allow for recommendations on which dust suppressant application techniques will work best in different situations.

The suppressant types investigated in this study are calcium chloride and magnesium chloride. It is recommended that, if possible, other types of dust suppressants used with CMAQ funds be evaluated. By collecting data on as many suppressant types as possible, conclusions can be reached on which dust control product works best for a given situation. The data analysis performed indicates that dust suppressant application rates are relatively standard for the counties tested. An effort should be made in the future to collect data on roads with application rates that fall outside this standard range. This will provide comparisons of contrasting application rates. It will also allow for recommendations to be made on what application rates will be the most effective in different situations. By determining the most efficient dust suppressants and application rates to use, standards can be established for dust control in Wyoming. This will help to ensure the cost-effective use of CMAQ funds in the future.

It is recommended that future data collection be performed in counties with high annual precipitation rates. By collecting and analyzing data from these counties, a better understanding can be reached on the effect precipitation has on dust suppressant effectiveness and longevity. Also, it is recommended that precipitation rates in the weeks leading up to the testing of a road be included in the data analysis. These values can be obtained from weather stations close to the testing area, and will help correlate precipitation with moisture content and dust concentrations. The results obtained from these values will be applicable to areas with high precipitation rates in the United States and worldwide.

The literature review suggests that vehicle speed directly affects the amount of dust generated on unpaved roads. Therefore, it is recommended that speed data collected with traffic counters be used to identify sections with high vehicle speeds. Posted speed limits should be documented on roads selected for testing, and compared with actual vehicle speeds found during data collection. This will aid in recognizing roads that have a problem with vehicles exceeding the posted speed limit. This will help counties in determining if speed control strategies should be used to help reduce dust generation on unpaved roads.

To enhance the cost effectiveness analysis, it is recommended that maintenance costs for roads be considered. Average costs for road maintenance can be compared before and after a road is treated with a dust suppressant. These data can be used to determine the effect dust treatment has on maintenance costs for unpaved roads. By including as many cost variables as possible, a more in-depth cost effectiveness analysis of Wyoming's CMAQ program can be conducted.

It is recommended that the data collection methods described in this paper be used in future efforts. By establishing a standard and accurate data collection process, counties can measure the long-term effectiveness of the CMAQ program. This will help in developing a long-term model for ranking what projects will be the most cost effective. By establishing an accurate model from historical data, counties will be able to use CMAQ funds and dust suppressants efficiently.

It is highly recommended that the study of the effectiveness of the CMAQ program in Wyoming be continued. The results will benefit states and counties in a number of ways. It will allow for selection of the best dust treatment based on aggregate properties, traffic composition, and climate. The results will also help in ranking dust treatments based on traffic characteristics. A comprehensive cost benefit analysis will aid in justifying chemical treatment costs to the public. Finally, it will provide information to the Federal Highway Administration (FHWA) to justify the CMAQ program

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APPENDIX A: PHASE 1: EPAM-5000 DATA

Average Dust Concentrations

County:	**Albany**			
Location Name:	**Construction Road**	**PM_{10} Concentration (mg/m^3)**		
Date:	MON 11-AUG-14	All Data	Average	0.516
Start:	10:07:14		Std. Dev.	1.495
End:	10:58:14	Above 0.5	Average	2.674
Data Type:	10.0 um - M	(Threshold)	Std. Dev.	2.798
Unit Type:	EPAM-5000	Peak Points	Average	5.947
Data Scale:	1		Std. Dev.	3.489

County:	**Albany**			
Location Name:	**Hornsby Road**	**PM_{10} Concentration (mg/m^3)**		
Date:	TUE 12-AUG-14	All Data	Average	0.112
Start:	13:46:38		Std. Dev.	0.350
End:	14:22:18	Above 0.5	Average	1.246
Data Type:	10.0 um - M	(Threshold)	Std. Dev.	0.468
Unit Type:	EPAM-5000	Peak Points	Average	1.525
Data Scale:	1		Std. Dev.	0.423

County:	**Albany**			
Location Name:	**Burbaker**	**PM_{10} Concentration (mg/m^3)**		
Date:	TUE 12-AUG-14	All Data	Average	0.074
Start:	12:32:59		Std. Dev.	0.253
End:	13:28:49	Above 0.5	Average	1.188
Data Type:	10.0 um - M	(Threshold)	Std. Dev.	0.554
Unit Type:	EPAM-5000	Peak Points	Average	1.424
Data Scale:	1		Std. Dev.	0.687

County:	**Albany**			
Location Name:	**Reservoir Road**	**PM_{10} Concentration (mg/m^3)**		
Date:	MON 11-AUG-14	All Data	Average	0.053
Start:	11:59:44		Std. Dev.	0.303
End:	12:58:44	Above 0.5	Average	2.003
Data Type:	10.0 um - M	(Threshold)	Std. Dev.	1.584
Unit Type:	EPAM-5000	Peak Points	Average	2.668
Data Scale:	1		Std. Dev.	1.739

County:	**Campbell**			
Location Name:	**Clarkelen (Untreated)**	**PM_{10} Concentration (mg/m^3)**		
Date:	WED 09-JUL-14	All Data	Average	0.126
Start:	13:34:40		Std. Dev.	0.422
End:	17:40:00	Above 0.5	Average	1.433
Data Type:	10.0 um - M	(Threshold)	Std. Dev.	0.898
Unit Type:	EPAM-5000	Peak Points	Average	1.776
Data Scale:	1		Std. Dev.	0.957

Location Number:	**Campbell**			
Location Name:	**Clarkelen (Treated)**	**PM_{10} Concentration (mg/m^3)**		
Date:	FRI 22-AUG-14	All Data	Average	0.011
Start:	9:50:24		Std. Dev.	0.011
End:	13:25:14	Above 0.01	Average	0.020
Data Type:	10.0 um - M	(Threshold)	Std. Dev.	0.012
Unit Type:	EPAM-5000	Peak Points	Average	0.031
Data Scale:	1		Std. Dev.	0.024

County:	**Campbell**			
Location Name:	**Cosner Road (Untreated)**	**PM_{10} Concentration (mg/m^3)**		
Date:	MON 25-AUG-14	All Data	Average	0.311
Start:	11:50:44		Std. Dev.	0.827
End:	15:35:14	Above 0.5	Average	1.846
Data Type:	10.0 um - M	(Threshold)	Std. Dev.	1.359
Unit Type:	EPAM-5000	Peak Points	Average	2.651
Data Scale:	1		Std. Dev.	1.642

County:	**Campbell**			
Location Name:	**Moore Road (Untreated)**	**PM_{10} Concentration (mg/m^3)**		
Date:	WED 09-JUL-14	All Data	Average	0.282
Start:	9:03:35		Std. Dev.	1.320
End:	12:54:35	Above 0.5	Average	3.043
Data Type:	10.0 um - M	(Threshold)	Std. Dev.	3.481
Unit Type:	EPAM-5000	Peak Points	Average	6.063
Data Scale:	1		Std. Dev.	4.596

County:	**Campbell**			
Location Name:	**Moore Road (Treated)**	**PM_{10} Concentration (mg/m^3)**		
Date:	FRI 22-AUG-14	All Data	Average	0.118
Start:	7:45:25		Std. Dev.	0.236
End:	9:24:05	Above 0.01	Average	0.141
Data Type:	10.0 um - M	(Threshold)	Std. Dev.	0.254
Unit Type:	EPAM-5000	Peak Points	Average	0.219
Data Scale:	1		Std. Dev.	0.187

Location Number:	**Converse**			
Location Name:	**Jenne Trail (Untreated)**	**PM_{10} Concentration (mg/m^3)**		
Date:	WED 02-JUL-14	All Data	Average	0.332
Start:	9:50:19		Std. Dev.	1.275
End:	13:46:49	Above 0.5	Average	2.674
Data Type:	10.0 um - M	(Threshold)	Std. Dev.	2.962
Unit Type:	EPAM-5000	Peak Points	Average	3.592
Data Scale:	1		Std. Dev.	3.750

County:	**Converse**			
Location Name:	**Jenne Trail, Treated**	**PM_{10} Concentration (mg/m^3)**		
Date:	THUR 14-AUG-14	All Data	Average	0.012
Start:	9:41:51		Std. Dev.	0.014
End:	12:05:31	Above 0.01	Average	0.029
Data Type:	10.0 um - M	(Threshold)	Std. Dev.	0.018
Unit Type:	EPAM-5000	Peak Points	Average	0.067
Data Scale:	1		Std. Dev.	0.038

County:	**Crook**			
Location Name:	**D-Road (Untreated)**	**PM_{10} Concentration (mg/m^3)**		
Date:	TUE 08-JUL-14	All Data	Average	0.097
Start:	10:47:28		Std. Dev.	0.437
End:	14:43:38	Above 0.5	Average	1.779
Data Type:	10.0 um - M	(Threshold)	Std. Dev.	1.277
Unit Type:	EPAM-5000	Peak Points	Average	2.282
Data Scale:	1		Std. Dev.	1.530

County:	**Crook**			
Location Name:	**D-Road (Treated)**	**PM_{10} Concentration (mg/m^3)**		
Date:	THUR 21-AUG-14	All Data	Average	0.210
Start:	14:41:08		Std. Dev.	0.023
End:	18:42:58	Above 0.01	Average	0.024
Data Type:	10.0 um - M	(Threshold)	Std. Dev.	0.022
Unit Type:	EPAM-5000	Peak Points	Average	0.245
Data Scale:	1		Std. Dev.	0.245

County:	**Lincoln**			
Location Name:	**Muddy Creek (Untreated)**	**PM_{10} Concentration (mg/m^3)**		
Date:	TUE 15-JUL-14	All Data	Average	0.044
Start:	15:59:44		Std. Dev.	0.150
End:	17:47:04	Above 0.5	Average	1.227
Data Type:	10.0 um - M	(Threshold)	Std. Dev.	0.628
Unit Type:	EPAM-5000	Peak Points	Average	1.050
Data Scale:	1		Std. Dev.	0.861

T-Tests: Untreated Roads

EPAM-5000 Dust Concentrations - Untreated Roads								
Location	Road	Average/Standard Deviation	4 Hour Collection Time	First 3 Hours	Last 3 Hours	First 2 Hours	Middle 2 Hours	Last 2 Hours
1	Clarkelen	Ave.	1.433	1.453	1.452	1.550	1.479	1.206
		Std. Dev.	0.898	0.914	0.935	0.980	0.959	0.655
2	Cosner	Ave.	1.846	1.838	1.850	1.778	1.840	1.942
		Std. Dev.	1.359	1.357	1.269	1.439	1.252	1.233
3	Moore	Ave.	3.043	2.989	2.451	3.209	2.114	2.557
		Std. Dev.	3.481	3.556	2.455	3.702	2.195	2.671
4	Jenne Trail	Ave.	2.674	2.887	2.824	2.334	3.189	2.598
		Std. Dev.	2.962	3.113	3.072	2.665	3.294	2.616
5	D-Road	Ave.	1.779	1.840	1.840	1.813	1.970	1.746
		Std. Dev.	1.277	1.345	1.360	1.238	1.494	1.314

4 hours vs first 3 hours

	Location				
	1	2	3	4	5
4 hr	1.433	1.846	3.043	2.674	1.779
1st 3 hr	1.453	1.838	2.989	2.887	1.840

t>tcrit	no
Pearson > 0.8	yes

t-Test: Paired Two Sample for Means

1st 3 hr

	Variable 1	*Variable 2*
Mean	2.16	2.20
Variance	0.45	0.48
Observations	5.00	5.00
Pearson Correlation	0.99	
Hypothesized Mean Difference	0.00	
df	4.00	
t Stat	-1.01	
P(T<=t) one-tail	0.19	
t Critical one-tail	2.13	
P(T<=t) two-tail	0.37	
t Critical two-tail	2.78	

4 hours vs last 3 hours

	Location				
	1	2	3	4	5
4 hr	1.433	1.846	3.043	2.674	1.779
last 3 hr	1.452	1.850	2.451	2.824	1.840

t>tcrit	no
Pearson > 0.8	yes

t-Test: Paired Two Sample for Means

2nd 3 hr

	Variable 1	*Variable 2*
Mean	2.16	2.08
Variance	0.45	0.30
Observations	5.00	5.00
Pearson Correlation	0.90	
Hypothesized Mean Difference	0.00	
df	4.00	
t Stat	0.54	
P(T<=t) one-tail	0.31	
t Critical one-tail	2.13	
P(T<=t) two-tail	0.62	
t Critical two-tail	2.78	

4 hours vs first 2 hours

	Location				
	1	2	3	4	5
4 hr	1.433	1.846	3.043	2.674	1.779
1st 2 hr	1.550	1.778	3.209	2.334	1.813

t>tcrit	no
Pearson > 0.8	yes

t-Test: Paired Two Sample for Means

1st 2 hr

	Variable 1	*Variable 2*
Mean	2.16	2.14
Variance	0.45	0.44
Observations	5.00	5.00
Pearson Correlation	0.96	
Hypothesized Mean Difference	0.00	
df	4.00	
t Stat	0.21	
P(T<=t) one-tail	0.42	
t Critical one-tail	2.13	
P(T<=t) two-tail	0.85	
t Critical two-tail	2.78	

4 hours vs middle 2 hours

			Location		
	1	2	3	4	5
4 hr	1.433	1.846	3.043	2.674	1.779
middle 2 hr	1.479	1.840	2.114	3.189	1.970

t>tcrit	no
Pearson > 0.8	no

t-Test: Paired Two Sample for Means
middle 2 hr

	Variable 1	*Variable 2*
Mean	2.16	2.12
Variance	0.45	0.41
Observations	5.00	5.00
Pearson Correlation	0.67	
Hypothesized Mean Difference	0.00	
df	4.00	
t Stat	0.15	
P(T<=t) one-tail	0.44	
t Critical one-tail	2.13	
P(T<=t) two-tail	0.89	
t Critical two-tail	2.78	

4 hours vs last 2 hours

			Location		
	1	2	3	4	5
4 hr	1.433	1.846	3.043	2.674	1.779
last 2 hr	1.206	1.942	2.557	2.598	1.746

t>tcrit	no
Pearson > 0.8	yes

t-Test: Paired Two Sample for Means
last 2 hr

	Variable 1	*Variable 2*
Mean	2.16	2.01
Variance	0.45	0.34
Observations	5.00	5.00
Pearson Correlation	0.95	
Hypothesized Mean Difference	0.00	
df	4.00	
t Stat	1.46	
P(T<=t) one-tail	0.11	
t Critical one-tail	2.13	
P(T<=t) two-tail	0.22	
t Critical two-tail	2.78	

First 3 hours vs. last 3 hours

			Location		
	1	2	3	4	5
1st 3 hr	1.453	1.838	2.989	2.887	1.840
last 3 hr	1.452	1.850	2.451	2.824	1.840

t>tcrit	no
Pearson > 0.8	yes

t-Test: Paired Two Sample for Means

	Variable 1	*Variable 2*
Mean	2.20	2.08
Variance	0.48	0.30
Observations	5.00	5.00
Pearson Correlation	0.95	
Hypothesized Mean Difference	0.00	
df	4.00	
t Stat	1.11	
P(T<=t) one-tail	0.16	
t Critical one-tail	2.13	
P(T<=t) two-tail	0.33	
t Critical two-tail	2.78	

First 3 hours vs. first 2 hours

			Location		
	1	2	3	4	5
1st 3 hr	1.453	1.838	2.989	2.887	1.840
1st 2 hr	1.550	1.778	3.209	2.334	1.813

t>tcrit	no
Pearson > 0.8	yes

t-Test: Paired Two Sample for Means

	Variable 1	*Variable 2*
Mean	2.20	2.14
Variance	0.48	0.44
Observations	5.00	5.00
Pearson Correlation	0.91	
Hypothesized Mean Difference	0.00	
df	4.00	
t Stat	0.49	
P(T<=t) one-tail	0.33	
t Critical one-tail	2.13	
P(T<=t) two-tail	0.65	
t Critical two-tail	2.78	

First 3 hours vs. middle 2 hours

	Location				
	1	2	3	4	5
1st 3 hr	1.453	1.838	2.989	2.887	1.840
middle 2 hr	1.479	1.840	2.114	3.189	1.970

t>tcrit	no
Pearson > 0.8	no

t-Test: Paired Two Sample for Means

	Variable 1	*Variable 2*
Mean	2.20	2.12
Variance	0.48	0.41
Observations	5.00	5.00
Pearson Correlation	0.77	
Hypothesized Mean Difference	0.00	
df	4.00	
t Stat	0.40	
P(T<=t) one-tail	0.35	
t Critical one-tail	2.13	
P(T<=t) two-tail	0.71	
t Critical two-tail	2.78	

First 3 hours vs. last 2 hours

	Location				
	1	2	3	4	5
1st 3 hr	1.453	1.838	2.989	2.887	1.840
last 2 hr	1.206	1.942	2.557	2.598	1.746

t>tcrit	no
Pearson > 0.8	yes

t-Test: Paired Two Sample for Means

	Variable 1	*Variable 2*
Mean	2.20	2.01
Variance	0.48	0.34
Observations	5.00	5.00
Pearson Correlation	0.96	
Hypothesized Mean Difference	0.00	
df	4.00	
t Stat	2.10	
P(T<=t) one-tail	0.05	
t Critical one-tail	2.13	
P(T<=t) two-tail	0.10	
t Critical two-tail	2.78	

Last 3 hours vs. first 2 hours

	Location				
	1	2	3	4	5
last 3 hr	1.452	1.850	2.451	2.824	1.840
1st 2 hr	1.550	1.778	3.209	2.334	1.813

t>tcrit	no
Pearson > 0.8	no

t-Test: Paired Two Sample for Means

	Variable 1	*Variable 2*
Mean	2.08	2.14
Variance	0.30	0.44
Observations	5.00	5.00
Pearson Correlation	0.74	
Hypothesized Mean Difference	0.00	
df	4.00	
t Stat	-0.26	
P(T<=t) one-tail	0.40	
t Critical one-tail	2.13	
P(T<=t) two-tail	0.81	
t Critical two-tail	2.78	

Last 3 hours vs. middle 2 hours

	Location				
	1	2	3	4	5
last 3 hr	1.452	1.850	2.451	2.824	1.840
middle 2 hr	1.479	1.840	2.114	3.189	1.970

t>tcrit	no
Pearson > 0.8	yes

t-Test: Paired Two Sample for Means

	Variable 1	*Variable 2*
Mean	2.08	2.12
Variance	0.30	0.41
Observations	5.00	5.00
Pearson Correlation	0.92	
Hypothesized Mean Difference	0.00	
df	4.00	
t Stat	-0.31	
P(T<=t) one-tail	0.39	
t Critical one-tail	2.13	
P(T<=t) two-tail	0.77	
t Critical two-tail	2.78	

Last 3 hours vs. last 2 hours

	Location				
	1	2	3	4	5
last 3 hr	1.452	1.850	2.451	2.824	1.840
last 2 hr	1.206	1.942	2.557	2.598	1.746

t>tcrit	no
Pearson > 0.8	yes

t-Test: Paired Two Sample for Means

	Variable 1	*Variable 2*
Mean	2.08	2.01
Variance	0.30	0.34
Observations	5.00	5.00
Pearson Correlation	0.96	
Hypothesized Mean Difference	0.00	
df	4.00	
t Stat	0.98	
P(T<=t) one-tail	0.19	
t Critical one-tail	2.13	
P(T<=t) two-tail	0.38	
t Critical two-tail	2.78	

T-Tests: Treated Roads

EPAM-5000 Dust Concentrations - Treated Roads									
Location	**Road**	**Average/Standard Deviation**	**4 Hour Collection Time**	**First 3 Hours**	**Last 3 Hours**	**First 2 Hours**	**Middle 2 Hours**	**Last 2 Hours**
1	Clarkelen	Ave.	0.020	0.021	0.017	0.021	0.018	0.017
		Std. Dev.	0.012	0.012	0.010	0.011	0.012	0.011
2	Cosner	Ave.	0.028	0.031	0.025	0.033	0.028	0.026
		Std. Dev.	0.019	0.020	0.019	0.015	0.021	0.020
3	Moore	Ave.	0.141	0.140	0.113	0.146	0.134	0.299
		Std. Dev.	0.254	0.260	0.223	0.248	0.287	0.410
4	Jenne Trail	Ave.	0.029	0.031	0.018	0.033	0.016	0.016
		Std. Dev.	0.018	0.031	0.018	0.033	0.016	0.016
5	D-Road	Ave.	0.024	0.024	0.020	0.028	0.020	0.020
		Std. Dev.	0.022	0.026	0.006	0.032	0.005	0.005

4 hours vs first 3 hours

	1	2	3	4	5
4 hr	0.020	0.028	0.141	0.029	0.024
1st 3 hr	0.021	0.031	0.141	0.031	0.024

t>tcrit	no
Pearson > 0.8	yes

t-Test: Paired Two Sample for Means

	Variable 1	*Variable 2*
Mean	0.048462951	0.049581556
Variance	0.002683371	0.002583783
Observations	5	5
Pearson Correlation	0.999842873	
Hypothesized Mean Difference	0	
df	4	
t Stat	-1.880599734	
P(T<=t) one-tail	0.06659444	
t Critical one-tail	2.131846786	
P(T<=t) two-tail	0.133188879	
t Critical two-tail	2.776445105	

4 hours vs last 3 hours

	1	2	3	4	5
4 hr	0.020	0.028	0.141	0.029	0.024
last 3 hr	0.017	0.025	0.113	0.018	0.020

t>tcrit	no
Pearson > 0.8	yes

t-Test: Paired Two Sample for Means

	Variable 1	*Variable 2*
Mean	0.048462951	0.038655473
Variance	0.002683371	0.001724892
Observations	5	5
Pearson Correlation	0.997545065	
Hypothesized Mean Difference	0	
df	4	
t Stat	2.035950445	
P(T<=t) one-tail	0.055727815	
t Critical one-tail	2.131846786	
P(T<=t) two-tail	0.11145563	
t Critical two-tail	2.776445105	

4 hours vs first 2 hours

	1	2	3	4	5
4 hr	0.020	0.028	0.141	0.029	0.024
1st 2 hr	0.021	0.033	0.146	0.033	0.028

t>tcrit	no
Pearson > 0.8	yes

t-Test: Paired Two Sample for Means

	Variable 1	*Variable 2*
Mean	0.048462951	0.05221195
Variance	0.002683371	0.002767169
Observations	5	5
Pearson Correlation	0.999555357	
Hypothesized Mean Difference	0	
df	4	
t Stat	-4.786418131	
P(T<=t) one-tail	0.004367205	
t Critical one-tail	2.131846786	
P(T<=t) two-tail	0.00873441	
t Critical two-tail	2.776445105	

4 hours vs middle 2 hours

	1	2	3	4	5
4 hr	0.020	0.028	0.141	0.029	0.024
middle 2 hr	0.018	0.028	0.134	0.016	0.020

t>tcrit	yes
Pearson > 0.8	yes

t-Test: Paired Two Sample for Means

	Variable 1	*Variable 2*
Mean	0.048462951	0.043181378
Variance	0.002683371	0.0026265
Observations	5	5
Pearson Correlation	0.994881447	
Hypothesized Mean Difference	0	
df	4	
t Stat	2.252813007	
P(T<=t) one-tail	0.043686295	
t Critical one-tail	2.131846786	
P(T<=t) two-tail	0.08737259	
t Critical two-tail	2.776445105	

4 hours vs last 2 hours

	1	2	3	4	5
4 hr	0.020	0.028	0.141	0.029	0.024
last 2 hr	0.017	0.026	0.299	0.016	0.020

t>tcrit	no
Pearson > 0.8	yes

t-Test: Paired Two Sample for Means

	Variable 1	*Variable 2*
Mean	0.048462951	0.075785356
Variance	0.002683371	0.015637417
Observations	5	5
Pearson Correlation	0.997721744	
Hypothesized Mean Difference	0	
df	4	
t Stat	-0.831791598	
P(T<=t) one-tail	0.226150132	
t Critical one-tail	2.131846786	
P(T<=t) two-tail	0.452300263	
t Critical two-tail	2.776445105	

First 3 hours vs. last 3 hours

	1	2	3	4	5
1st 3 hr	0.021	0.031	0.141	0.031	0.024
last 3 hr	0.017	0.025	0.113	0.018	0.020

t>tcrit	yes
Pearson > 0.8	yes

t-Test: Paired Two Sample for Means

	Variable 1	*Variable 2*
Mean	0.049781556	0.038655473
Variance	0.002629272	0.001724892
Observations	5	5
Pearson Correlation	0.997377837	
Hypothesized Mean Difference	0	
df	4	
t Stat	2.414998701	
P(T<=t) one-tail	0.036578906	
t Critical one-tail	2.131846786	
P(T<=t) two-tail	0.073157812	
t Critical two-tail	2.776445105	

First 3 hours vs. first 2 hours

	1	2	3	4	5
1st 3 hr	0.021	0.031	0.141	0.031	0.024
1st 2 hr	0.021	0.033	0.146	0.033	0.028

t>tcrit	no
Pearson > 0.8	yes

t-Test: Paired Two Sample for Means

	Variable 1	*Variable 2*
Mean	0.049781556	0.05221195
Variance	0.002629272	0.002767169
Observations	5	5
Pearson Correlation	0.999680766	
Hypothesized Mean Difference	0	
df	4	
t Stat	-2.91140464	
P(T<=t) one-tail	0.021808396	
t Critical one-tail	2.131846786	
P(T<=t) two-tail	0.043616792	
t Critical two-tail	2.776445105	

First 3 hours vs. middle 2 hours

	1	2	3	4	5
1st 3 hr	0.021	0.031	0.141	0.031	0.024
middle 2 hr	0.018	0.028	0.134	0.016	0.020

t>tcrit	yes
Pearson > 0.8	yes

t-Test: Paired Two Sample for Means

	Variable 1	*Variable 2*
Mean	0.049781556	0.043181378
Variance	0.002629272	0.0026265
Observations	5	5
Pearson Correlation	0.994736373	
Hypothesized Mean Difference	0	
df	4	
t Stat	2.805912594	
P(T<=t) one-tail	0.024259199	
t Critical one-tail	2.131846786	
P(T<=t) two-tail	0.048518398	
t Critical two-tail	2.776445105	

First 3 hours vs. last 2 hours

	1	2	3	4	5
1st 3 hr	0.021	0.031	0.141	0.031	0.024
last 2 hr	0.017	0.026	0.299	0.016	0.020

t>tcrit	no
Pearson > 0.8	yes

t-Test: Paired Two Sample for Means

	Variable 1	*Variable 2*
Mean	0.049781556	0.075785356
Variance	0.002629272	0.015637417
Observations	5	5
Pearson Correlation	0.996852126	
Hypothesized Mean Difference	0	
df	4	
t Stat	-0.78526872	
P(T<=t) one-tail	0.238099535	
t Critical one-tail	2.131846786	
P(T<=t) two-tail	0.47619907	
t Critical two-tail	2.776445105	

Last 3 hours vs. first 2 hours

	1	2	3	4	5
last 3 hr	0.017	0.025	0.113	0.018	0.020
1st 2 hr	0.021	0.033	0.146	0.033	0.028

t>tcrit	no
Pearson > 0.8	yes

t-Test: Paired Two Sample for Means

	Variable 1	*Variable 2*
Mean	0.038655473	0.05221195
Variance	0.001724892	0.002767169
Observations	5	5
Pearson Correlation	0.997178941	
Hypothesized Mean Difference	0	
df	4	
t Stat	-2.6097447	
P(T<=t) one-tail	0.029717964	
t Critical one-tail	2.131846786	
P(T<=t) two-tail	0.059435928	
t Critical two-tail	2.776445105	

Last 3 hours vs. middle 2 hours

	1	2	3	4	5
last 3 hr	0.017	0.025	0.113	0.018	0.020
middle 2 hr	0.018	0.028	0.134	0.016	0.020

t>tcrit	no
Pearson > 0.8	yes

t-Test: Paired Two Sample for Means

	Variable 1	*Variable 2*
Mean	0.038655473	0.043181378
Variance	0.001724892	0.0026265
Observations	5	5
Pearson Correlation	0.99938996	
Hypothesized Mean Difference	0	
df	4	
t Stat	-1.02740498	
P(T<=t) one-tail	0.181147968	
t Critical one-tail	2.131846786	
P(T<=t) two-tail	0.362295936	
t Critical two-tail	2.776445105	

Last 3 hours vs. last 2 hours

	1	2	3	4	5
last 3 hr	0.017	0.025	0.113	0.018	0.020
last 2 hr	0.017	0.026	0.299	0.016	0.020

t>tcrit	no
Pearson > 0.8	yes

t-Test: Paired Two Sample for Means

	Variable 1	*Variable 2*
Mean	0.038655473	0.075785356
Variance	0.001724892	0.015637417
Observations	5	5
Pearson Correlation	0.998728266	
Hypothesized Mean Difference	0	
df	4	
t Stat	-0.99315833	
P(T<=t) one-tail	0.188424162	
t Critical one-tail	2.131846786	
P(T<=t) two-tail	0.376848324	
t Critical two-tail	2.776445105	

APPENDIX B: PHASE 2: CORRELATION STUDY DATA

EPAM-5000 Data: Treated Sections

County:	**Albany**	**PM_{10} Concentration (mg/m^3)**		
Location Name:	**Sand Creek - Treated**	Above	Average	0.016
Date:	FRI 26-SEP-14	0.01	Std. Dev.	0.008
Dustometer Screen	#38			
Start:	18:13:33			
End:	18:46:08			
Data Type:	10.0 um - M			
Unit Type:	EPAM-5000			
Data Scale:	1			

County:	**Albany**	**PM_{10} Concentration (mg/m^3)**		
Location Name:	**Curtis - Treated**	Above	Average	0.028
Date:	WED 24-SEP-14	0.01	Std. Dev.	0.019
Dustometer Screen	#38			
Start:	13:43:53			
End:	17:24:23			
Data Type:	10.0 um - M			
Unit Type:	EPAM-5000			
Data Scale:	1			

County:	**Albany**	**PM_{10} Concentration (mg/m^3)**		
Location Name:	**CR51 - Treated**	Above	Average	0.029
Date:	THUR 14-AUG-14	0.01	Std. Dev.	0.018
Dustometer Screen	#38			
Start:	9:41:51			
End:	12:05:31			
Data Type:	10.0 um - M			
Unit Type:	EPAM-5000			
Data Scale:	1			

County:	**Albany**	**PM_{10} Concentration (mg/m^3)**		
Location Name:	**Mason Lane - Treated**	Above	Average	0.051
Date:	TUE 30-SEP-14	0.01	Std. Dev.	0.062
Dustometer Screen	#38			
Start:	8:37:51			
End:	9:05:48			
Data Type:	10.0 um - M			
Unit Type:	EPAM-5000			
Data Scale:	1			

Location Number:	**Albany**	**PM_{10} Concentration (mg/m^3)**		
Location Name:	**Curtis - Treated**	Above	Average	0.032
Date:	TUE 14-OCT-14	0.01	Std. Dev.	0.053
Dustometer Screen	#200			
Start:	14:19:51			
End:	14:48:26			
Data Type:	10.0 um - M			
Unit Type:	EPAM-5000			
Data Scale:	1			

Location Number:	**Albany**	**PM_{10} Concentration (mg/m^3)**		
Location Name:	**310 Mason - Treated**	Above	Average	0.059
Date:	WED 15-OCT-14	0.01	Std. Dev.	0.122
Dustometer Screen	#200			
Start:	10:59:46			
End:	11:28:28			
Data Type:	10.0 um - M			
Unit Type:	EPAM-5000			
Data Scale:	1			

Location Number:	**Albany**	**PM_{10} Concentration (mg/m^3)**		
Location Name:	**CR-51 - Treated**	Above	Average	0.040
Date:	TUE 14-OCT-14	0.01	Std. Dev.	0.050
Dustometer Screen	#200			
Start:	11:49:03			
End:	12:16:23			
Data Type:	10.0 um - M			
Unit Type:	EPAM-5000			
Data Scale:	1			

Location Number:	**Albany**	**PM_{10} Concentration (mg/m^3)**		
Location Name:	**Sand Creek - Treated**	Above	Average	0.023
Date:	WED 15-OCT-14	0.01	Std. Dev.	0.027
Dustometer Screen	#200			
Start:	12:35:05			
End:	12:58:07			
Data Type:	10.0 um - M			
Unit Type:	EPAM-5000			
Data Scale:	1			

Location Number:	**Albany**	**PM_{10} Concentration (mg/m^3)**		
Location Name:	**Burbaker - Treated**	Above	Average	0.033
Date:	WED 15-OCT-14	0.01	Std. Dev.	0.049
Dustometer Screen	#200			
Start:	12:08:40			
End:	12:26:18			
Data Type:	10.0 um - M			
Unit Type:	EPAM-5000			
Data Scale:	1			

CSU Dustometer Data: Treated Sections

County:	Albany		
Road:	Sand Creek - T		
Condition:	Treated		
Screen Size	#38		
Distance (mi)	Weight Before (g)	Weight After (g)	Concentration (g/mi)
1	12.93	13.35	0.42
1	12.97	13.2	0.23
1	12.98	13.15	0.17
		Average	0.27
		Std Dev	0.11

County:	Albany		
Road:	CR - 51		
Condition:	Treated		
Screen Size	#38		
Distance (mi)	Weight Before (g)	Weight After (g)	Concentration (g/mi)
1	12.93	13.78	0.85
1	12.97	13.98	1.01
1	12.98	13.59	0.61
		Average	0.82
		Std Dev	0.16

County:	Albany		
Road:	Mason Lane		
Condition:	Treated		
Screen Size	#38		
Distance (mi)	Weight Before (g)	Weight After (g)	Concentration (g/mi)
1	12.93	15.32	2.39
1	12.97	15.62	2.65
1	12.98	15.71	2.73
		Average	2.59
		Std Dev	0.15

County:	Albany
Road:	Curtis
Condition:	Treated
Screen Size	#38

Distance (mi)	Weight Before (g)	Weight After (g)	Concentration (g/mi)
1	12.93	13.82	0.89
1	12.97	14.05	1.08
1	12.98	14.08	1.10
		Average	1.02
		Std Dev	0.09

County:	Albany
Road:	Burbaker
Condition:	Treated
Screen Size	#200

Distance (mi)	Weight Before (g)	Weight After (g)	Concentration (g/mi)
1	12.8	13.97	1.17
1	12.8	13.86	1.06
1	12.9	14.11	1.21
		Average	1.15
		Std Dev	0.06

County:	Albany
Road:	Sand Creek
Condition:	Treated
Screen Size	#200

Distance (mi)	Weight Before (g)	Weight After (g)	Concentration (g/mi)
1	12.93	14.69	1.76
1	12.93	15	2.07
1	12.8	15.05	2.25
		Average	2.03
		Std Dev	0.20

County:	Albany		
Road:	CR - 51		
Condition:	Treated		
Screen Size	#200		
Distance (mi)	Weight Before (g)	Weight After (g)	Concentration (g/mi)
1	12.82	13.61	0.79
1	12.95	13.82	0.87
1	12.87	13.91	1.04
		Average	0.90
		Std Dev	0.10

County:	Albany		
Road:	Mason Lane		
Condition:	Treated		
Screen Size	#200		
Distance (mi)	Weight Before (g)	Weight After (g)	Concentration (g/mi)
1	12.71	12.98	0.27
1	12.96	13.44	0.48
1	12.87	13.06	0.19
		Average	0.31
		Std Dev	0.12

County:	Albany		
Road:	Curtis		
Condition:	Treated		
Screen Size	#200		
Distance (mi)	Weight Before (g)	Weight After (g)	Concentration (g/mi)
1	12.81	14.5	1.69
1	12.78	13.76	0.98
1	12.78	14.68	1.9
		Average	1.52
		Std Dev	0.39

EPAM-5000 Data: Untreated Sections

County:	**Albany**			
Location Name:	**Construction Road**	**PM_{10} Concentration (mg/m^3)**		
Date:	MON 11-AUG-14	Above 0.5	Average	2.674
Start:	10:07:14	(Threshold)	Std. Dev.	2.798
End:	10:58:14			
Data Type:	10.0 um - M			
Unit Type:	EPAM-5000			
Data Scale:	1			

County:	**Albany**	**PM_{10} Concentration (mg/m^3)**		
Location Name:	**Hornsby Road**	Above 0.5	Average	1.246
Date:	TUE 12-AUG-14	(Threshold)	Std. Dev.	0.468
Start:	13:46:38			
End:	14:22:18			
Data Type:	10.0 um - M			
Unit Type:	EPAM-5000			
Data Scale:	1			

County:	**Albany**	**PM_{10} Concentration (mg/m^3)**		
Location Name:	**Reservoir Road**	Above 0.5	Average	2.003
Date:	MON 11-AUG-14	(Threshold)	Std. Dev.	1.584
Start:	11:59:44			
End:	12:58:44			
Data Type:	10.0 um - M			
Unit Type:	EPAM-5000			
Data Scale:	1			

County:	**Albany**	**PM_{10} Concentration (mg/m^3)**		
Location Name:	**E. Curtis**	Above 0.5	Average	1.817
Date:	THUR 25-SEP-14	(Threshold)	Std. Dev.	1.467
Start:	11:02:51			
End:	11:29:40			
Data Type:	10.0 um - M			
Unit Type:	EPAM-5000			
Data Scale:	1			

County:	**Albany**	**PM_{10} Concentration (mg/m^3)**		
Location Name:	**Welsh**	Above 0.5	Average	1.775
Date:	THUR 25-SEP-14	(Threshold)	Std. Dev.	1.253
Start:	11:34:08			
End:	11:44:20			
Data Type:	10.0 um - M			
Unit Type:	EPAM-5000			
Data Scale:	1			

County:	**Albany**	**PM_{10} Concentration (mg/m^3)**		
Location Name:	**Sand Creek (1)**	Above 0.5	Average	1.092
Date:	FRI 26-SEP-14	(Threshold)	Std. Dev.	0.652
Start:	12:22:02			
End:	12:59:44			
Data Type:	10.0 um - M			
Unit Type:	EPAM-5000			
Data Scale:	1			

County:	**Albany**	**PM_{10} Concentration (mg/m^3)**		
Location Name:	**CR - 51**	Above 0.5	Average	1.838
Date:	FRI 26-SEP-14	(Threshold)	Std. Dev.	1.348
Start:	17:17:33			
End:	17:48:48			
Data Type:	10.0 um - M			
Unit Type:	EPAM-5000			
Data Scale:	1			

County:	**Albany**	**PM_{10} Concentration (mg/m^3)**		
Location Name:	**Burbaker**	Above 0.5	Average	1.188
Date:	TUE 12-AUG-14	(Threshold)	Std. Dev.	0.554
Start:	12:32:59			
End:	13:28:49			
Data Type:	10.0 um - M			
Unit Type:	EPAM-5000			
Data Scale:	1			

County:	**Albany**	**PM_{10} Concentration (mg/m^3)**		
Location Name:	**Burbaker (2)**	Above 0.5	Average	0.411
Date:	FRI 26-SEP-14	(Threshold)	Std. Dev.	0.269
Start:	11:46:49			
End:	12:09:15			
Data Type:	10.0 um - M			
Unit Type:	EPAM-5000			
Data Scale:	1			

County:	**Albany**	**PM_{10} Concentration (mg/m^3)**		
Location Name:	**310 Mason Lane**	Above 0.5	Average	0.820
Date:	FRI 26-SEP-14	(Threshold)	Std. Dev.	0.251
Start:	10:51:08			
End:	11:15:54			
Data Type:	10.0 um - M			
Unit Type:	EPAM-5000			
Data Scale:	1			

CSU Dustometer Data: Untreated Sections

County:	Albany		
Road:	Construction Road		
Condition:	Untreated		
Screen Size	#38		
Distance (mi)	Weight Before (g)	Weight After (g)	Concentration (g/mi)
1	13.51	16.93	3.42
1	13.54	16.5	2.96
1	13.62	16.74	3.12
1	13.64	17.07	3.43
1	13.49	16.82	3.33
1	13.49	17.08	3.59
		Average =	3.31
		std dev =	0.21

County:	Albany		
Road:	Reservoir Road		
Condition:	Untreated		
Screen Size	#38		
Distance (mi)	Weight Before (g)	Weight After (g)	Concentration (g/mi)
0.7	13.74	15.80	2.06
0.7	13.72	16.28	2.56
0.7	13.6	17.39	3.79
0.7	13.6	15.09	1.49
0.7	13.57	15.21	1.64
0.7	13.48	14.98	1.50
		Average =	2.17
		std dev =	0.81

County:	Albany		
Road:	Burbaker		
Condition:	Untreated		
Screen Size	#38		
Distance (mi)	Weight Before (g)	Weight After (g)	Concentration (g/mi)
1	12.89	13.45	0.56
1	13.64	14.43	0.79
1	13.57	14.2	0.63
1	12.89	13.4	0.51
1	13.63	14.44	0.81
1	12.86	13.58	0.72
		Average =	0.67
		std dev =	0.11

County:	Albany		
Road:	Hornsby		
Condition:	Untreated		
Screen Size	#38		
Distance (mi)	Weight Before (g)	Weight After (g)	Concentration (g/mi)
1	12.83	13.47	0.64
1	12.84	13.77	0.93
1	12.73	13.64	0.91
1	12.95	14.1	1.15
1	12.86	14.61	1.75
1	12.87	14.4	1.53
		Average =	1.15
		std dev =	0.38

County:	Albany		
Road:	E. Curtis		
Condition:	Untreated		
Screen Size	#38		
Distance (mi)	Weight Before (g)	Weight After (g)	Concentration (g/mi)
1	12.66	14.95	2.29
1	13.55	16.04	2.49
1	12.83	14.14	1.31
		Average	2.03
		Std Dev	0.52

County:	Albany		
Road:	Welsh		
Condition:	Untreated		
Screen Size	#38		
Distance (mi)	Weight Before (g)	Weight After (g)	Concentration (g/mi)
1	12.81	15.92	3.11
1	13.61	17.27	3.66
1	12.85	15.82	2.97
		Average	3.25
		Std Dev	0.30

County:	Albany		
Road:	310 Mason Ln		
Condition:	Untreated		
Screen Size	#38		
Distance (mi)	Weight Before (g)	Weight After (g)	Concentration (g/mi)
1	12.71	13.54	0.83
1	12.84	13.49	0.65
1	12.76	13.98	1.22
		Average	0.90
		Std Dev	0.24

County:	Albany		
Road:	Burbaker (2)		
Condition:	Untreated		
Screen Size	#38		
Distance (mi)	Weight Before (g)	Weight After (g)	Concentration (g/mi)
1	13.02	13.2	0.18
1	12.91	13.44	0.53
1	12.89	13.11	0.22
		Average	0.31
		Std Dev	0.16

County:	Albany		
Road:	Sand Creek		
Condition:	Untreated		
Screen Size	#38		
Distance (mi)	Weight Before (g)	Weight After (g)	Concentration (g/mi)
1	12.81	14.5	1.69
1	12.78	13.76	0.98
1	12.78	14.68	1.9
		Average	1.52
		Std Dev	0.39

County: Albany
Road: CR-51
Condition: Untreated
Screen Size #38

Distance (mi)	Weight Before (g)	Weight After (g)	Concentration (g/mi)
1	12.88	16.42	3.54
1	12.93	14.22	1.29
1	12.91	15.87	2.96
		Average	2.60
		Std Dev	0.95

Regression Analysis in R

Road	EPAM	Dustometer	Moisture	Wind	Passing200	Temp
Construction Rd.	2.674	3.31	1.74	0.4	6.5	72.25
Burbaker	1.188	0.67	1.03	3.7	12.5	80.25
Hornsby	1.246	1.15	0.71	2.6	15.1	83
Reservoir	2.003	2.17	2.40	2.0	21.3	72
Curtis	1.817	2.03	0.74	11.8	23.1	69.4
Welsh	1.775	3.25	0.66	3.2	11.0	76.7
Mason	0.820	0.90	2.16	5.3	13.9	75.7
Burbaker (2)	0.411	0.31	0.53	4.7	12.5	77.3
SandCreek1	1.092	1.52	0.90	7.1	10.8	81.3
CR - 51	1.838	2.60	0.52	2.9	14.3	80.7
Jenne Trail	2.674	1.80	1.50	9.5	14.1	76.0
Cosner	1.846	3.98	2.10	3.8	11.6	72.5
Muddy Creek	1.227	2.45	1.62	18.2	19.4	82.3

Explanation of Data

EPAM:	Average concentration of dust from EPAM-5000 using threshold method (mg/m3)
Dustometer:	Average concentration of dust from CSU dustometer (g/mi)
Moisture:	Average moisture percentage of road aggregate (%)
Wind:	Average wind speed during data collection (mph)
Passing200:	Percent of total aggregate passing #200 (75 μm) sieve (%)
Temp:	Average temperature during data collection

```
> input=read.table("correlation.data.txt",header=T,sep='')

> Dustometer=input$Dustometer

> EPAM=input$EPAM

> Moisture=input$Moisture

> Wind=input$Wind

> Fines=input$Passing200

> Temp=input$Temp       #Define Variables


> model=lm(Dustometer~EPAM+Moisture+Wind+Fines+Temp) #create model from all
variables


##########################################################################

> step(model,k=2)  #AIC Model
```

```
Start:  AIC=-6.22

Dustometer ~ EPAM + Moisture + Wind + Fines + Temp


           Df Sum of Sq    RSS     AIC

- Wind      1    0.0019 1.6184 -8.2114

- Temp      1    0.0232 1.6398 -8.0804

- Moisture  1    0.1431 1.7597 -7.3747

- Fines     1    0.1828 1.7994 -7.1516

<none>                  1.6165 -6.2231

- EPAM      1    4.2609 5.8774  4.6853


Step:  AIC=-8.21

Dustometer ~ EPAM + Moisture + Fines + Temp


           Df Sum of Sq    RSS     AIC

- Temp      1    0.0441 1.6625 -9.9428

- Fines     1    0.2072 1.8256 -9.0067

- Moisture  1    0.2386 1.8570 -8.8363

<none>                  1.6184 -8.2114
```

```
- EPAM      1    5.7679 7.3863  4.9704

Step:  AIC=-9.94
Dustometer ~ EPAM + Moisture + Fines

           Df Sum of Sq    RSS      AIC
- Fines     1    0.1632 1.8257 -11.0064
- Moisture  1    0.1946 1.8571 -10.8359
<none>                  1.6625  -9.9428
- EPAM      1    8.0673 9.7297   5.7260

Step:  AIC=-11.01
Dustometer ~ EPAM + Moisture

           Df Sum of Sq    RSS      AIC
- Moisture  1    0.2423 2.0680 -11.7601
<none>                  1.8257 -11.0064
- EPAM      1    8.1249 9.9506   3.9505
```

```
Step:  AIC=-11.76

Dustometer ~ EPAM



       Df Sum of Sq    RSS      AIC

<none>               2.068 -11.7601

- EPAM  1    7.9515 10.020   2.0195



Call:

lm(formula = Dustometer ~ EPAM)



Coefficients:

(Intercept)         EPAM

    -0.3324       1.4285

############################################################
> step(model,k=log(length(Dustometer)))   #Best BIC Model

Start:  AIC=-4.41

Dustometer ~ EPAM + Moisture + Wind + Fines + Temp



           Df Sum of Sq    RSS     AIC
```

```
- Wind      1    0.0019 1.6184 -6.6985

- Temp      1    0.0232 1.6398 -6.5675

- Moisture  1    0.1431 1.7597 -5.8618

- Fines     1    0.1828 1.7994 -5.6386

<none>                  1.6165 -4.4076

- EPAM      1    4.2609 5.8774  6.1983


Step:  AIC=-6.7

Dustometer ~ EPAM + Moisture + Fines + Temp


           Df Sum of Sq    RSS     AIC

- Temp      1    0.0441 1.6625 -8.7324

- Fines     1    0.2072 1.8256 -7.7963

- Moisture  1    0.2386 1.8570 -7.6260

<none>                  1.6184 -6.6985

- EPAM      1    5.7679 7.3863  6.1808


Step:  AIC=-8.73

Dustometer ~ EPAM + Moisture + Fines
```

```
           Df Sum of Sq    RSS      AIC
- Fines     1    0.1632 1.8257 -10.0986
- Moisture  1    0.1946 1.8571  -9.9282
<none>                  1.6625  -8.7324
- EPAM      1    8.0673 9.7297   6.6338

Step:  AIC=-10.1
Dustometer ~ EPAM + Moisture

           Df Sum of Sq    RSS      AIC
- Moisture  1    0.2423 2.0680 -11.1549
<none>                  1.8257 -10.0986
- EPAM      1    8.1249 9.9506   4.5556

Step:  AIC=-11.15
Dustometer ~ EPAM

       Df Sum of Sq    RSS      AIC
```

```
<none>               2.068 -11.1549

- EPAM  1    7.9515 10.020   2.3221


Call:

lm(formula = Dustometer ~ EPAM)


Coefficients:

(Intercept)         EPAM

    -0.3324       1.4285


> ######## Both AIC and BIC find best model is direct correlation ###########

>

> model=lm(Dustometer~EPAM) #Create correlation model based on step functions

> summary(model)


Call:

lm(formula = Dustometer ~ EPAM)


Residuals:
```

```
     Min       1Q   Median       3Q      Max
-0.69473 -0.28150 -0.06114  0.23455  1.04672

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)  -0.3324     0.4152  -0.800 0.446576
EPAM          1.4285     0.2576   5.546 0.000543 ***
---

Residual standard error: 0.5084 on 8 degrees of freedom
Multiple R-squared:  0.7936,    Adjusted R-squared:  0.7678
F-statistic: 30.76 on 1 and 8 DF,  p-value: 0.0005434
```

APPENDIX C: CMAQ ROADS – TREATMENT INFORMATION & DUST CONCENTRATIONS

Treatment costs

County:	**Lincoln**
Road:	**Muddy Creek**
Treatment Type	Magnesium Chloride
Cost Per Mile	$2,700.00
Road Width (ft)	19.86
Cost Per Mile-foot	$135.95
Application Rate (gsy)	0.5

County:	**Lincoln**
Road:	**Gomer**
Treatment Type	Magnesium Chloride
Cost Per Mile	$4,960.42
Road Width (ft)	23.66
Cost Per Mile-foot	$209.65
Application Rate (gsy)	0.5

County:	**Lincoln**
Road:	**Sublett-Pomeroy Basin**
Treatment Type	Magnesium Chloride
Cost Per Mile	$4,960.42
Road Width (ft)	24.56
Cost Per Mile-foot	$201.97
Application Rate (gsy)	0.5

County:	**Converse**
Road:	**Jenne Trail**
Treatment Type	Calcium Chloride
Cost Per Mile	$5,280.00
Road Width (ft)	33.57
Cost Per Mile-foot	$157.28
Application Rate (gsy)	0.4

County:	**Converse**
Road:	**Ross**
Treatment Type	Calcium Chloride
Cost Per Mile	$5,808.00
Road Width (ft)	32.82
Cost Per Mile-foot	$176.97
Application Rate (gsy)	0.4

County:	**Crook**
Road:	**D-Road**
Treatment Type	Magnesium Chloride
Cost Per Mile	$6,265.60
Road Width (ft)	32.26
Cost Per Mile-foot	$194.22
Application Rate (gsy)	0.50

County:	**Campbell**
Road:	**Cosner**
Treatment Type	Magnesium Chloride
Cost Per Mile	$5,367.23
Road Width (ft)	30.04
Cost Per Mile-foot	$178.67
Application Rate (gsy)	0.5

County:	**Campbell**
Road:	**Clarkelen**
Treatment Type	Magnesium Chloride
Cost Per Mile	$5,367.23
Road Width (ft)	30.88
Cost Per Mile-foot	$173.81
Application Rate (gsy)	0.5

County:	**Campbell**
Road:	**Moore**
Treatment Type	Magnesium Chloride
Cost Per Mile	$5,367.23
Road Width (ft)	25.17
Cost Per Mile-foot	$213.24
Application Rate (gsy)	0.5

County:	**Campbell**
Road:	**Todd**
Treatment Type	Magnesium Chloride
Cost Per Mile	$5,703.95
Road Width (ft)	25.69
Cost Per Mile-foot	$222.03
Application Rate (gsy)	0.5

County:	**Campbell**
Road:	**Turnercrest**
Treatment Type	Magnesium Chloride
Cost Per Mile	$5,703.95
Road Width (ft)	25.37
Cost Per Mile-foot	$224.83
Application Rate (gsy)	0.5

County:	**Campbell**
Road:	**Hayden**
Treatment Type	Magnesium Chloride
Cost Per Mile	$5,703.95
Road Width (ft)	25.95
Cost Per Mile-foot	$219.81
Application Rate (gsy)	0.5

County:	**Campbell**
Road:	**Christensen**
Treatment Type	Magnesium Chloride
Cost Per Mile	$5,703.95
Road Width (ft)	28.37
Cost Per Mile-foot	$201.06
Application Rate (gsy)	0.5

County:	**Campbell**
Road:	**Black & Yellow**
Treatment Type	Magnesium Chloride
Cost Per Mile	$5,703.95
Road Width (ft)	27.01
Cost Per Mile-foot	$211.18
Application Rate (gsy)	0.5

County:	**Johnson**
Road:	**TTT Road**
Treatment Type	Calcium Chloride
Cost Per Mile	$4,675.00
Road Width (ft)	25
Cost Per Mile-foot	$187.00
Application Rate (gsy)	0.45

County:	**Sweetwater**
Road:	**Patrick Draw**
Treatment Type	Magnesium Chloride
Cost Per Mile	$3,111.11
Road Width (ft)	21
Cost Per Mile-foot	$148.15
Application Rate (gsy)	0.47

County:	**Weston**
Road:	Bruce
Treatment Type	Calcium Chloride
Cost Per Mile	$6,004.79
Road Width (ft)	27.35
Cost Per Mile-foot	$219.55
Application Rate (gsy)	0.5

County:	**Campbell**
Road:	**Iberlin**
Treatment Type	Magnesium Chloride
Cost Per Mile	$5,703.95
Road Width (ft)	32.15
Cost Per Mile-foot	$177.42
Application Rate (gsy)	0.5

County:	**Sweetwater**
Road:	**Wamsutter S**
Treatment Type	Magnesium Chloride
Cost Per Mile	$5,711.79
Road Width (ft)	30.01
Cost Per Mile-foot	$190.33
Application Rate (gsy)	0.47

County:	**Weston**
Road:	**Grieves**
Treatment Type	Calcium Chloride
Cost Per Mile	$6,186.85
Road Width (ft)	27.92
Cost Per Mile-foot	$221.59
Application Rate (gsy)	0.5

County:	**Weston**
Road:	**Mush Creek**
Treatment Type	Calcium Chloride
Cost Per Mile	$5,422.73
Road Width (ft)	24.1
Cost Per Mile-foot	$225.01
Application Rate (gsy)	0.5

County:	**Lincoln**	**PM_{10} Concentration (mg/m^3)**		
Location Name:	**Muddy Creek**	Above 0.5	Average	2.277
Date:	TUE 15-JUL-14	(Threshold)	Std. Dev.	0.628
Road Condition:	Untreated			
Start:	15:59:44			
End:	17:47:04			
Data Type:	10.0 um - M			
Unit Type:	EPAM-5000			
Data Scale:	1			

County:	**Lincoln**	**PM_{10} Concentration (mg/m^3)**		
Location Name:	**Gomer**	Above 0.5	Average	0.973
Date:	FRI 05-JUN-15	(Threshold)	Std. Dev.	0.477
Road Condition:	Untreated			
Start:	7:08:04			
End:	10:47:54			
Data Type:	10.0 um - M			
Unit Type:	EPAM-5000			
Data Scale:	1			

County:	**Lincoln**			
Location Name:	**Sublett-Pomeroy**	**PM_{10} Concentration (mg/m^3)**		
Date:	FRI 05-JUN-15		Average	0.927
Road Condition:	Untreated	Above 0.5		
Start:	6:31:43	(Threshold)	Std. Dev.	0.456
End:	9:28:53			
Data Type:	10.0 um - M			
Unit Type:	EPAM-5000			
Data Scale:	1			

County:	**Converse**	**PM_{10} Concentration (mg/m^3)**		
Location Name:	**Jenne Trail**	Above 0.5	Average	2.674
Date:	WED 02-JUL-14	(Threshold)	Std. Dev.	2.962
Road Condition:	Untreated			
Start:	9:50:19			
End:	13:46:49			
Data Type:	10.0 um - M			
Unit Type:	EPAM-5000			
Data Scale:	1			

County:	**Converse**	**PM_{10} Concentration (mg/m^3)**		
Location Name:	**Ross**	Above 0.5	Average	0.914
Date:	MON 01-JUN-15	(Threshold)	Std. Dev.	0.438
Road Condition:	Untreated			
Start:	14:52:57			
End:	17:48:37			
Data Type:	10.0 um - M			
Unit Type:	EPAM-5000			
Data Scale:	1			

County:	**Crook**	**PM_{10} Concentration (mg/m^3)**		
Location Name:	**D-Road**	Above 0.5	Average	1.779
Date:	TUE 08-JUL-14	(Threshold)	Std. Dev.	1.277
Road Condition:	Untreated			
Start:	10:47:28			
End:	14:43:38			
Data Type:	10.0 um - M			
Unit Type:	EPAM-5000			
Data Scale:	1			

County:	**Campbell**	**PM_{10} Concentration (mg/m^3)**		
Location Name:	**Cosner**	Above 0.5	Average	1.846
Date:	MON 25-AUG-14	(Threshold)	Std. Dev.	1.359
Road Condition:	Untreated			
Start:	11:50:44			
End:	15:35:14			
Data Type:	10.0 um - M			
Unit Type:	EPAM-5000			
Data Scale:	1			

County:	**Campbell**	**PM_{10} Concentration (mg/m^3)**		
Location Name:	Clarkelen	Above 0.5	Average	1.433
Date:	WED 09-JUL-14	(Threshold)	Std. Dev.	0.898
Road Condition:	Untreated			
Start:	13:34:40			
End:	17:40:00			
Data Type:	10.0 um - M			
Unit Type:	EPAM-5000			
Data Scale:	1			

County:	**Campbell**	**PM_{10} Concentration (mg/m^3)**		
Location Name:	Moore Road	Above 0.5	Average	3.043
Date:	WED 09-JUL-14	(Threshold)	Std. Dev.	3.481
Road Condition:	Untreated			
Start:	9:03:35			
End:	12:54:35			
Data Type:	10.0 um - M			
Unit Type:	EPAM-5000			
Data Scale:	1			

County:	**Campbell**	**PM_{10} Concentration (mg/m^3)**		
Location Name:	**Turnercrest**	Above 0.5	Average	2.017
Date:	WED 17-JUN-15	(Threshold)	Std. Dev.	1.440
Road Condition:	Untreated			
Start:	16:19:29			
End:	19:16:39			
Data Type:	10.0 um - M			
Unit Type:	EPAM-5000			
Data Scale:	1			

County:	**Campbell**	**PM_{10} Concentration (mg/m^3)**		
Location Name:	**Todd**	Above 0.5	Average	1.287
Date:	FRI 19-JUN-15	(Threshold)	Std. Dev.	0.862
Road Condition:	Untreated			
Start:	6:32:48			
End:	9:21:18			
Data Type:	10.0 um - M			
Unit Type:	EPAM-5000			
Data Scale:	1			

County:	**Campbell**	**PM_{10} Concentration (mg/m^3)**		
Location Name:	**Christensen**	Above 0.5	Average	3.010
Date:	THUR 18-JUN-15	(Threshold)	Std. Dev.	2.638
Road Condition:	Untreated			
Start:	8:08:44			
End:	10:57:34			
Data Type:	10.0 um - M			
Unit Type:	EPAM-5000			
Data Scale:	1			

County:	**Campbell**	**PM_{10} Concentration (mg/m^3)**		
Location Name:	**Hayden**	Above 0.5	Average	1.870
Date:	TUE 02-JUN-15	(Threshold)	Std. Dev.	1.285
Road Condition:	Untreated			
Start:	6:42:54			
End:	9:36:24			
Data Type:	10.0 um - M			
Unit Type:	EPAM-5000			
Data Scale:	1			

County:	**Campbell**	**PM_{10} Concentration (mg/m^3)**		
Location Name:	**Black & Yellow Road**	Above 0.5	Average	1.471
Date:	TUE 02-JUN-15	(Threshold)	Std. Dev.	1.227
Road Condition:	Untreated			
Start:	9:59:55			
End:	12:52:45			
Data Type:	10.0 um - M			
Unit Type:	EPAM-5000			
Data Scale:	1			

County:	**Campbell**	**PM_{10} Concentration (mg/m^3)**		
Location Name:	**Iberlin**	Above 0.5	Average	4.036
Date:	TUE 02-JUN-15	(Threshold)	Std. Dev.	3.668
Road Condition:	Untreated			
Start:	13:11:40			
End:	16:12:10			
Data Type:	10.0 um - M			
Unit Type:	EPAM-5000			
Data Scale:	1			

County:	**Johnson**	**PM_{10} Concentration (mg/m^3)**		
Location Name:	**TTT Road**	Above 0.5	Average	2.166
Date:	THUR 18-JUN-15	(Threshold)	Std. Dev.	2.065
Road Condition:	Untreated			
Start:	12:35:41			
End:	15:43:21			
Data Type:	10.0 um - M			
Unit Type:	EPAM-5000			
Data Scale:	1			

County:	**Sweetwater**	**PM_{10} Concentration (mg/m^3)**		
Location Name:	**Wamsutter**	Above 0.5	Average	1.330
Date:	TUE 26-MAY-15	(Threshold)	Std. Dev.	0.837
Road Condition:	Untreated			
Start:	13:08:40			
End:	16:09:30			
Data Type:	10.0 um - M			
Unit Type:	EPAM-5000			
Data Scale:	1			

County:	**Sweetwater**	**PM_{10} Concentration (mg/m^3)**		
Location Name:	**Patrick Draw**	Above 0.5	Average	1.673
Date:	THUR 28-MAY-15	(Threshold)	Std. Dev.	0.196
Road Condition:	Untreated			
Start:	10:52:53			
End:	13:40:03			
Data Type:	10.0 um - M			
Unit Type:	EPAM-5000			
Data Scale:	1			

County:	**Weston**	**PM_{10} Concentration (mg/m^3)**		
Location Name:	**Grieves**	Above 0.5	Average	2.383
Date:	WED 01-JUL-15	(Threshold)	Std. Dev.	3.450
Road Condition:	Untreated			
Start:	10:45:00			
End:	13:58:40			
Data Type:	10.0 um - M			
Unit Type:	EPAM-5000			
Data Scale:	1			

County:	**Weston**	**PM_{10} Concentration (mg/m^3)**		
Location Name:	**Bruce**	Above 0.5	Average	1.270
Date:	WED 01-JUL-15	(Threshold)	Std. Dev.	0.650
Road Condition:	Untreated			
Start:	7:27:08			
End:	10:16:18			
Data Type:	10.0 um - M			
Unit Type:	EPAM-5000			
Data Scale:	1			

County:	**Weston**	**PM_{10} Concentration (mg/m^3)**		
Location Name:	**Mush Creek**	Above 0.5	Average	2.371
Date:	WED 01-JUL-15	(Threshold)	Std. Dev.	2.085
Road Condition:	Untreated			
Start:	17:32:40			
End:	19:58:20			
Data Type:	10.0 um - M			
Unit Type:	EPAM-5000			
Data Scale:	1			

EPAM Data: Treated Roads

County:	**Lincoln**	**PM_{10} Concentration (mg/m^3)**		
Location Name:	**Muddy Creek**	Above	Average	0.051
Date:	TUE 30-SEP-14	0.01	Std. Dev.	0.062
Road Condition:	Treated			
Start:	8:37:51			
End:	9:05:48			
Data Type:	10.0 um - M			
Unit Type:	EPAM-5000			
Data Scale:	1			

Location Number:	**Lincoln**	**PM_{10} Concentration (mg/m^3)**		
Location Name:	**Gomer**	Above	Average	0.023
Date:	WED 24-JUN-15	0.01	Std. Dev.	0.039
Road Condition:	Treated			
Start:	10:33:55			
End:	13:39:05			
Data Type:	10.0 um - M			
Unit Type:	EPAM-5000			
Data Scale:	1			

Location Number:	**Lincoln**	**PM_{10} Concentration (mg/m^3)**		
Location Name:	**Sublette-Pomeroy**	Above	Average	0.032
Date:	WED 24-JUN-15	0.01	Std. Dev.	0.045
Road Condition:	Treated			
Start:	7:01:59			
End:	10:14:09			
Data Type:	10.0 um - M			
Unit Type:	EPAM-5000			
Data Scale:	1			

Location Number:	**Converse**	**PM_{10} Concentration (mg/m^3)**		
Location Name:	**Jenne Trail**	Above	Average	0.029
Date:	THUR 14-AUG-14	0.01	Std. Dev.	0.018
Road Condition:	Treated			
Start:	9:41:51			
End:	12:05:31			
Data Type:	10.0 um - M			
Unit Type:	EPAM-5000			
Data Scale:	1			

Location Number:	**Crook County**	**PM_{10} Concentration (mg/m^3)**		
Location Name:	**D-Road**	Above	Average	0.024
Date:	THUR 21-AUG-14	0.01	Std. Dev.	0.022
Road Condition:	Treated			
Start:	14:41:08			
End:	18:42:58			
Data Type:	10.0 um - M			
Unit Type:	EPAM-5000			
Data Scale:	1			

Location Number:	**Campbell**	**PM_{10} Concentration (mg/m^3)**		
Location Name:	**Cosner**	Above	Average	0.028
Date:	WED 24-SEP-14	0.01	Std. Dev.	0.019
Road Condition:	Treated			
Start:	13:43:53			
End:	17:24:23			
Data Type:	10.0 um - M			
Unit Type:	EPAM-5000			
Data Scale:	1			

Location Number:	**Campbell**	**PM_{10} Concentration (mg/m^3)**		
Location Name:	**Clarkelen**	Above	Average	0.020
Date:	FRI 22-AUG-14	0.01	Std. Dev.	0.012
Road Condition:	Treated			
Start:	9:50:24			
End:	13:25:14			
Data Type:	10.0 um - M			
Unit Type:	EPAM-5000			
Data Scale:	1			

Location Number:	**Campbell**	**PM_{10} Concentration (mg/m^3)**		
Location Name:	**Moore**	Above	Average	0.141
Date:	FRI 22-AUG-14	0.01	Std. Dev.	0.254
Road Condition:	Treated			
Start:	7:45:25			
End:	9:24:05			
Data Type:	10.0 um - M			
Unit Type:	EPAM-5000			
Data Scale:	1			

CSU Dustometer Data: Untreated Roads

County:	Lincoln		
Road:	Muddy Creek		
Condition:	Untreated		
Screen Size:	#38		
Distance (mi)	Weight Before (g)	Weight After (g)	Concentration (g/mi)
1	13.6	16.05	2.45
		Average	2.45

County:	Lincoln						
Road:	Gomer						
Condition:	Untreated						
Screen Size:	#38			Screen Size:	#200		
Distance (mi)	Weight Before (g)	Weight After (g)	Concentration (g/mi)	Distance (mi)	Weight Before (g)	Weight After (g)	Concentration (g/mi)
1	14.7	16.2	1.5	1	14.6	15.6	1
1	14.6	15.5	0.9	1	14.7	15.4	0.7
1	14.7	16.4	1.7	1	14.6	16.5	1.9
		Average	1.37			Average	1.20
		std dev	0.34			std dev	0.51

County:	Lincoln						
Road:	Sublette-Pomeroy						
Condition:	Untreated						
Screen Size:	#38			Screen Size:	#200		
Distance (mi)	Weight Before (g)	Weight After (g)	Concentration (g/mi)	Distance (mi)	Weight Before (g)	Weight After (g)	Concentration (g/mi)
1	14.7	17.2	2.5	1	14.7	17.8	3.1
1	14.6	15.8	1.2	1	14.7	16.9	2.2
1	15.5	16.6	1.1	1	14.7	16.6	1.9
		Average	1.60			Average	2.40
		std dev	0.64			std dev	0.51

County:	Converse		
Road:	Jenne Trail		
Condition:	Untreated		
Screen Size:	#38		
Distance (mi)	Weight Before (g)	Weight After (g)	Concentration (g/mi)
1	13.56	14.35	0.79
1	13.61	14.4	0.79
1	13.58	17.4	3.82
		Average	1.8
		std dev	1.428355698

County:	Converse							
Road:	Ross							
Condition:	Untreated							
Screen Size:	#38				Screen Size:	#200		
Distance (mi)	Weight Before (g)	Weight After (g)	Concentration (g/mi)		Distance (mi)	Weight Before (g)	Weight After (g)	Concentration (g/mi)
1	14.7	15.1	0.4		1	14.6	15.1	0.5
1	14.6	15.3	0.7		1	14.5	15	0.5
1	14.5	15.4	0.9		1	14.5	15.4	0.9
		Average	0.67				Average	0.63
		std dev	0.21				std dev	0.19

County:	Campbell		
Road:	Cosner		
Condition:	Untreated		
Screen Size:	#38		
Distance (mi)	Weight Before (g)	Weight After (g)	Concentration (g/mi)
1	12.97	15.78	2.81
1	12.88	18.02	5.14
		Average	3.975
		std dev	1.165

County:	Campbell							
Road:	Turnercrest							
Condition:	Untreated							
Screen Size:	#38				Screen Size:	#200		
Distance (mi)	Weight Before (g)	Weight After (g)	Concentration (g/mi)		Distance (mi)	Weight Before (g)	Weight After (g)	Concentration (g/mi)
1	14.6	15.4	0.8		1	14.6	16.3	1.7
1	14.6	15.9	1.3		1	14.7	15.8	1.1
1	14.7	15.2	0.5		1	14.7	15.4	0.7
		Average	0.87				Average	1.17
		std dev	0.33				std dev	0.41

County:	Campbell							
Road:	Todd							
Condition:	Untreated							
Screen Size:	#38				Screen Size:	#200		
Distance (mi)	Weight Before (g)	Weight After (g)	Concentration (g/mi)		Distance (mi)	Weight Before (g)	Weight After (g)	Concentration (g/mi)
1	14.7	15.2	0.5		1	14.6	16.5	1.9
1	14.6	15.8	1.2		1	14.7	16.2	1.5
1	14.6	15.3	0.7		1	14.7	16.9	2.2
		Average	0.80				Average	1.87
		std dev	0.29				std dev	0.29

County:	Campbell							
Road:	Christensen							
Condition:	Untreated							
Screen Size:	#38				Screen Size:	#200		
Distance (mi)	Weight Before (g)	Weight After (g)	Concentration (g/mi)		Distance (mi)	Weight Before (g)	Weight After (g)	Concentration (g/mi)
1	14.6	16.9	2.3		1	14.7	16.9	2.2
1	14.6	16	1.4		1	14.6	18	3.4
1	14.7	16.2	1.5		1	14.7	16.6	1.9
		Average	1.73				Average	2.50
		std dev	0.40				std dev	0.65

County:	Campbell						
Road:	Hayden						
Condition:	Untreated						
Screen Size:	#38			Screen Size:	#200		
Distance (mi)	Weight Before (g)	Weight After (g)	Concentration (g/mi)	Distance (mi)	Weight Before (g)	Weight After (g)	Concentration (g/mi)
1	14.6	16.9	2.3	1	14.6	16.4	1.8
1	14.6	16.4	1.8	1	14.8	16.4	1.6
1	14.6	17.1	2.5	1	14.6	16.3	1.7
		Average	2.20			Average	1.70
		std dev	0.29			std dev	0.08

County:	Campbell						
Road:	Black & Yellow						
Condition:	Untreated						
Screen Size:	#38			Screen Size:	#200		
Distance (mi)	Weight Before (g)	Weight After (g)	Concentration (g/mi)	Distance (mi)	Weight Before (g)	Weight After (g)	Concentration (g/mi)
1	14.6	15.7	1.1	1	14.6	16.5	1.9
1	14.6	15.5	0.9	1	14.6	15.8	1.2
1	14.6	15.7	1.1	1	14.5	15.8	1.3
		Average	1.03			Average	1.47
		std dev	0.09			std dev	0.31

County:	Campbell						
Road:	Iberlin						
Condition:	Untreated						
Screen Size:	#38			Screen Size:	#200		
Distance (mi)	Weight Before (g)	Weight After (g)	Concentration (g/mi)	Distance (mi)	Weight Before (g)	Weight After (g)	Concentration (g/mi)
1	14.5	15.4	0.9	1	14.5	15.2	0.7
1	14.5	15.4	0.9	1	14.7	15	0.3
1	14.6	15.2	0.6	1	14.7	15.4	0.7
		Average	0.80			Average	0.57
		std dev	0.14			std dev	0.19

County:	Johnson						
Road:	TTT						
Condition:	Untreated						
Screen Size:	#38			Screen Size:	#200		
Distance (mi)	Weight Before (g)	Weight After (g)	Concentration (g/mi)	Distance (mi)	Weight Before (g)	Weight After (g)	Concentration (g/mi)
1	14.6	15.6	1	1	14.4	15.7	1.3
1	14.7	16	1.3	1	14.6	15.6	1
1	14.7	17.2	2.5	1	14.5	16.1	1.6
		Average	1.60			Average	1.30
		std dev	0.65			std dev	0.24

County:	Sweetwater						
Road:	Wamsutter						
Condition:	Untreated						
Screen Size:	#38			Screen Size:	#200		
Distance (mi)	Weight Before (g)	Weight After (g)	Concentration (g/mi)	Distance (mi)	Weight Before (g)	Weight After (g)	Concentration (g/mi)
1	13	17.93	4.93	1	12.97	15.29	2.32
1	12.67	15.21	2.54	1	13.02	15.45	2.43
1	12.7	17.16	4.46	1	13.07	15.34	2.27
		Average	3.98			Average	2.34
		std dev	1.03			std dev	0.07

County:	Sweetwater						
Road:	Patrick Draw						
Condition:	Untreated						
Screen Size:	#38			Screen Size:	#200		
Distance (mi)	Weight Before (g)	Weight After (g)	Concentration (g/mi)	Distance (mi)	Weight Before (g)	Weight After (g)	Concentration (g/mi)
1	13	16.73	3.73	1	12.94	15.09	2.15
1	12.67	15.61	2.94	1	12.96	15.27	2.31
1	12.7	16.35	3.65	1	12.89	15.18	2.29
		Average	3.44			Average	2.25
		std dev	0.36			std dev	0.07

County:	Weston						
Road:	Grieves						
Condition:	Untreated						
Screen Size:	#38			Screen Size:	#200		
Distance (mi)	Weight Before (g)	Weight After (g)	Concentration (g/mi)	Distance (mi)	Weight Before (g)	Weight After (g)	Concentration (g/mi)
1	14.5	17.2	2.7	1	14.6	17.4	2.8
1	14.5	16.7	2.2	1	14.5	16.3	1.8
1	14.6	17	2.4	1	14.5	16.7	2.2
		Average	2.43			Average	2.27
		std dev	0.21			std dev	0.41

County:	Weston						
Road:	Bruce						
Condition:	Untreated						
Screen Size:	#38			Screen Size:	#200		
Distance (mi)	Weight Before (g)	Weight After (g)	Concentration (g/mi)	Distance (mi)	Weight Before (g)	Weight After (g)	Concentration (g/mi)
1	14.6	17.2	2.6	1	14.6	17.3	2.7
1	14.6	16.4	1.8	1	14.5	16.9	2.4
1	14.6	17.6	3	1	14.5	17	2.5
		Average	2.47			Average	2.53
		std dev	0.50			std dev	0.12

County:	Weston						
Road:	Mush Creek						
Condition:	Untreated						
Screen Size:	#38			Screen Size:	#200		
Distance (mi)	Weight Before (g)	Weight After (g)	Concentration (g/mi)	Distance (mi)	Weight Before (g)	Weight After (g)	Concentration (g/mi)
1	14.7	17.4	2.7	1	12.84	17.1	4.26
1	14.5	17.3	2.8	1	14.6	18.3	3.7
1	14.6	16.5	1.9	1	12.82	17.6	4.78
		Average	2.47			Average	4.25
		std dev	0.40			std dev	0.44

CSU Dustometer Data: Treated Roads

County:	Lincoln		
Road:	Muddy Creek		
Condition:	Treated		
Screen Size:	#38		
Distance (mi)	Weight Before (g)	Weight After (g)	Concentration (g/mi)
0.5	12.9	13.28	0.38
0.5	12.92	13.17	0.25
0.5	12.9	13.24	0.34
		Average	0.65
		Std Dev	0.11

County:	Lincoln						
Road:	Gomer						
Condition:	Treated						
Screen Size:	#38			Screen Size:	#200		
Distance (mi)	Weight Before (g)	Weight After (g)	Concentration (g/mi)	Distance (mi)	Weight Before (g)	Weight After (g)	Concentration (g/mi)
1	12.79	13	0.21	1	12.79	12.9	0.11
1	12.82	13.2	0.38	1	12.96	13.2	0.24
1	12.8	13	0.2	1	12.8	13	0.2
		Average	0.26			Average	0.18
		std dev	0.08			std dev	0.05

County:	Lincoln						
Road:	Sublette-Pomeroy						
Condition:	Treated						
Screen Size:	#38			Screen Size:	#200		
Distance (mi)	Weight Before (g)	Weight After (g)	Concentration (g/mi)	Distance (mi)	Weight Before (g)	Weight After (g)	Concentration (g/mi)
1	14.7	15.3	0.6	1	14.6	14.8	0.2
1	14.6	15.1	0.5	1	14.7	14.8	0.1
1	14.6	15	0.4	1	14.6	14.8	0.2
		Average	0.50			Average	0.17
		std dev	0.08			std dev	0.05

County:	Converse		
Road:	Jenne Trail		
Condition:	Treated		
Screen Size:	#38		
Distance (mi)	Weight Before (g)	Weight After (g)	Concentration (g/mi)
1	12.85	13.7	0.85
1	12.82	14.22	1.4
1	12.91	13.12	0.21
		Average	0.82
		std dev	0.49

County:	Campbell		
Road:	Cosner		
Condition:	Treated		
Screen Size:	#38		
Distance (mi)	Weight Before (g)	Weight After (g)	Concentration (g/mi)
1	13.6	13.62	0.02
1	13.54	13.58	0.04
1	13.62	13.62	0
		Average	0.02
		Std Dev	0.016329932

APPENDIX D: CMAQ ROADS – TRAFFIC VOLUMES

Per-Vehicle Summary Report: LINCOLN, GOMER

Station ID : LIN-GOM-U

Last Connected Device Type Apollo

Info Line 1 :
Info Line 2 :
GPS Lat/Lon :
DB File : LIN-GOM-U.DB

Version Number : 1.66
Serial Number : 11297
Number of Lanes : 2
Posted Speed Limi 0.0 mph

Lane Configuration

#	*Dir.*	*Information*	*Vehicle Sensors*	*Sensor Spacing*	*Loop Length*
1.00			Axle-Axle	4.0 ft	
3.00			Axle-Axle	4.0 ft	

Average Daily Traffic (ADT)

	Weekday			Weekend		Total ADT		
	Cars :	80	100%	Cars :		Cars :	**80**	100%
Trucks :		0	0%	Trucks :		Trucks :	**0**	0%
	Total :	80		Total :		Total :	**80**	

Speed Totals

50 % :	39.5 mph	Top Speed :	40.8 mph		Average Truck Speed :	
85 % :	40.5 mph	Low Speed :	21.6 mph		Average Car Speed :	37.7 mph
Avg :	37.7 mph	10mph Pace Speed:	36.5 - 46.4	90.00%		

Peak Hour Totals

AM Peak Hour (Volume)
Weekday : 10:00 - 11:00 (Avg 14)
Weekend :

AM Peak Hour (Speed)
07:30 - 08:30 (40.3 mph)

PM Peak Hour (Volume)

Weekday :
Weekend :

PM Peak Hour (Speed)

Grand Totals

Total Cars :	10 (	80 ADT)	Average Length :	11.4 ft	Average Headway :	756.1 sec
Total Trucks :	0 (	0 ADT)	Average Axles :	2.00	Average (	755.9 sec
Total Volume :	10 (	80 ADT)				

Per-Vehicle Summary Report: LINCOLN, SUBLETTE-POMEROY

Station ID : LIN-SUB-U

Last Connected Device Type Apollo

Info Line 1 :
Info Line 2 :
GPS Lat/Lon :
DB File : LIN-SUB-U.DB

Version Number : 1.66
Serial Number : 11166
Number of Lanes : 2
Posted Speed Limi 0.0 mph

Lane Configuration

#	*Dir.*	*Information*	*Vehicle Sensors*	*Sensor Spacing*	*Loop Length*
1.00			Axle-Axle	4.0 ft	
3.00			Axle-Axle	4.0 ft	

Average Daily Traffic (ADT)

	Weekday			Weekend		Total ADT		
	Cars :	112	93%	Cars :		Cars :	**112**	93%
Trucks :		8	7%	Trucks :		Trucks :	**8**	7%
	Total :	120		Total :		Total :	**120**	

Speed Totals

50 % :	36.0 mph	Top Speed :	51.1 mph		Average Truck Speed :	15.5 mph
85 % :	38.8 mph	Low Speed :	15.5 mph		Average Car Speed :	35.4 mph
Avg :	34.1 mph	10mph Pace Speed:	35.9 - 45.8	53.30%		

Peak Hour Totals

AM Peak Hour (Volume)
Weekday : 08:30 - 09:30 (Avg 10)
Weekend :

AM Peak Hour (Speed)
08:15 - 09:15 (37.1 mph)

PM Peak Hour (Volume)

Weekday :
Weekend :

PM Peak Hour (Speed)

Grand Totals

Total Cars :	14 (	112 ADT)	Average Length :	17.9 ft	Average Headway :	474.6 sec
Total Trucks :	1 (	8 ADT)	Average Axles :	2.40	Average (	474.2 sec
Total Volume :	15 (	120 ADT)				

Per-Vehicle Summary Report: CONVERSE, JENNE TRAIL

Station ID : CON-JEN-T

Last Connected Device Type : Apollo

Info Line 1 :
Info Line 2 :
GPS Lat/Lon :
DB File : CON-JEN-T.DB

Version Number : 1.51
Serial Number : 11194
Number of Lanes : 2
Posted Speed Limit : 0.0 mph

Lane Configuration

#	Dir.	Information	Vehicle Sensors	Sensor Spaci	Loop Length
1.00			Axle-Axle	4.0 ft	
3.00			Axle-Axle	4.0 ft	

Average Daily Traffic (ADT)

	Weekday			Weekend		Total ADT		
	Cars :	296	55%	Cars :		Cars :	**296**	55%
Trucks :		240	45%	Trucks :		Trucks :	**240**	45%
	Total :	536		Total :		Total :	**536**	

Speed Totals

50 % :	34.9 mph	Top Speed :	56.0 mph		Average Truck Speed :	30.1 mph
85 % :	43.5 mph	Low Speed :	6.3 mph		Average Car Speed :	36.8 mph
Avg :	33.8 mph	10mph Pace Speed:	34.5 - 44.4	38.80%		

Peak Hour Totals

AM Peak Hour (Volume)			AM Peak Hour (Speed)	
Weekday :	10:00 - 11:00	(Avg 33)	11:00 - 12:00	(34.7 mph)
Weekend :				
PM Peak Hour (Volume)			PM Peak Hour (Speed)	
Weekday :	12:00 - 13:00	(Avg 20)	12:00 - 13:00	(33.5 mph)
Weekend :				

Grand Totals

Total Cars :	37 (	296 ADT)	Average Leng	31.9 ft	Average Headway :	122.7 sec
Total Trucks :	30 (	240 ADT)	Average Axle	3.40	Average Gap :	122.0 sec
Total Volume :	67 (	536 ADT)				

Per-Vehicle Summary Report: CONVERSE, ROSS

Station ID : CON-ROS-U

Last Connected Device Type : Apollo

Info Line 1 :
Info Line 2 :
GPS Lat/Lon :
DB File : CON-ROS-U.DB

Version Number : 1.66
Serial Number : 11166
Number of Lanes : 2
Posted Speed Limi 0.0 mph

Lane Configuration

#	Dir.	Information	Vehicle Sensors	Sensor Spacing	Loop Length
1.00			Axle-Axle	4.0 ft	
3.00			Axle-Axle	4.0 ft	

Average Daily Traffic (ADT)

	Weekday			Weekend		Total ADT		
	Cars :	376	63%	Cars :		Cars :	**376**	63%
Trucks :		216	37%	Trucks :		Trucks :	**216**	37%
	Total :	592		Total :		Total :	**592**	

Speed Totals

50 % :	32.3 mph	Top Speed :	47.7 mph		Average Truck Speed :	29.6 mph
85 % :	38.2 mph	Low Speed :	10.7 mph		Average Car Speed :	32.5 mph
Avg :	31.4 mph	10mph Pace Speed:	30.2 - 40.1	55.40%		

Peak Hour Totals

AM Peak Hour (Volume)			AM Peak Hour (Speed)	
Weekday :				
Weekend :				
PM Peak Hour (Volume)			PM Peak Hour (Speed)	
Weekday :	17:30 - 18:30	(Avg 36)	16:00 - 17:00	(35.6 mph)
Weekend :				

Grand Totals

Total Cars :	47 (	376 ADT)	Average Length :	26.1 ft	Average Headway :	125.7 sec
Total Trucks :	27 (	216 ADT)	Average Axles :	3.00	Average (	125.1 sec
Total Volume :	74 (	592 ADT)				

Per-Vehicle Summary Report: CAMPBELL, TURNERCREST

Station ID : CAM-TUR-U

Last Connected Device Type : Apollo

Info Line 1 :
Info Line 2 :
GPS Lat/Lon :
DB File : CAM-TUR-U.DB

Version Number : 1.66
Serial Number : 11297
Number of Lanes : 2
Posted Speed Limit : 0.0 mph

Lane Configuration

#	Dir.	Information	Vehicle Sensors	Sensor Spacing	Loop Length
1.00			Axle-Axle	4.0 ft	
3.00			Axle-Axle	4.0 ft	

Average Daily Traffic (ADT)

	Weekday			Weekend	Total ADT		
	Cars :	252	87%	Cars :	Cars :	**252**	87%
Trucks :		36	13%	Trucks :	Trucks :	**36**	13%
	Total :	288		Total :	Total :	**288**	

Speed Totals

50 % :	38.2 mph	Top Speed :	51.6 mph		Average Truck Speed :	35.9 mph
85 % :	43.6 mph	Low Speed :	18.1 mph		Average Car Speed :	37.7 mph
Avg :	37.4 mph	10mph Pace Speed:	34.9 - 44.8	70.80%		

Peak Hour Totals

AM Peak Hour (Volume)			AM Peak Hour (Speed)	
Weekday :				
Weekend :				
PM Peak Hour (Volume)			PM Peak Hour (Speed)	
Weekday :	16:30 - 17:30	(Avg 30)	16:15 - 17:15	(38.6 mph)
Weekend :				

Grand Totals

Total Cars :	42	(	252	ADT)	Average Length : 16.2 ft	Average Headway :	186.9 sec
Total Trucks :	6	(	36	ADT)	Average Axles : 2.30	Average Gap :	186.6 sec
Total Volume :	48	(	288	ADT)			

Per-Vehicle Summary Report: CROOK, D-ROAD

Station ID : CRO-D-T

Last Connected Device Type : Apollo

Info Line 1 :
Info Line 2 :
GPS Lat/Lon :
DB File : CRO-D-T.DB

Version Number : 1.51
Serial Number : 11194
Number of Lanes : 2
Posted Speed Limit : 0.0 mph

Lane Configuration

#	Dir.	Information	Vehicle Sensors	Sensor Spacing	Loop Length
1.00			Axle-Axle		4.0 ft
3.00			Axle-Axle		4.0 ft

Average Daily Traffic (ADT)

	Weekday			Weekend	Total ADT		
	Cars :	324	84%	Cars :	Cars :	**324**	84%
Trucks :		60	16%	Trucks :	Trucks :	**60**	16%
	Total :	384		Total :	Total :	**384**	

Speed Totals

50 % :	52.6 mph	Top Speed :	82.1 mph		Average Truck Speed :	43.6 mph
85 % :	62.1 mph	Low Speed :	9.9 mph		Average Car Speed :	54.9 mph
Avg :	53.1 mph	10mph Pace Speed:	49.8 - 59.7	48.40%		

Peak Hour Totals

AM Peak Hour (Volume)			AM Peak Hour (Speed)	
Weekday :				
Weekend :				
PM Peak Hour (Volume)			PM Peak Hour (Speed)	
Weekday :	18:30 - 19:30	(Avg 28)	14:15 - 1!	(57.0 mph)
Weekend :				

Grand Totals

Total Cars :	54	(	324	ADT)	Average Length : 18.4 ft	Average Headway :	203.4 sec
Total Trucks :	10	(	60	ADT)	Average Axles : 2.60	Average Gap :	203.2 sec
Total Volume :	64	(	384	ADT)			

Per-Vehicle Summary Report: CAMPBELL, CLARKELEN

Station ID:	CAM-CLA-T
Info Line 1:	Clarkelen
Info Line 2:	
Counter Type:	Apollo
Counter Version:	1.51
Serial #:	11194
Latitude:	
Longitude:	
Lanes:	2
Speed Limit:	

LANE CONFIGURATION:

Lane #	Dir	Informatio	Sensors	Spacing	Loop Leng	Comment
1			Ax-Ax	4.0 ft		
3			Ax-Ax	4.0 ft		

AVERAGE DAILY TRAFFIC (ADT):

	Weekday	%		Weekend	%		Total ADT	%
Cars:	252	37.5	Cars:			Cars:	252	37.5
Trucks:	420	62.5	Trucks:			Trucks:	420	62.5
Total:	672		Total:			Total:	672	

SPEED TOTALS:

50 %:	39.5	mph	Top Speed:	60.7	mph			Avg Truck Speed:	36.2	mph
85 %:	47.8	mph	Low Speed:	7.5	mph		%	Avg Car Speed:	44.8	mph
Avg:	39.5	mph	10mph Pace Speed:	32.7	42.6	48.2				

PEEK HOUR TOTALS:

AM Peak Hour (Volume):			Avg	AM Peak Hour (Speed):			
Weekday: 11:00	12:00	31		9:15	10:15	45.5	mph
Weekend:							
PM Peak Hour (Volume):			Avg	PM Peak Hour (Speed):			
Weekday: 13:15	14:15	52		12:30	13:30	41.9	mph
Weekend:							

GRAND TOTALS:

Total Cars:	42	252	(ADT)	Average Length:	37.0 ft	Average Headway:	110.4 sec
Total Trucks:	70	420	(ADT)	Average Axles:	3.8	Average Gap:	109.7 sec
Total Volume:	112	672					

Per-Vehicle Summary Report: CAMPBELL, COSNER

Info Line 1:	Cosner
Info Line 2:	
Counter Type:	Apollo
Counter Version:	1.51
Serial #:	11286
Latitude:	
Longitude:	
Lanes:	2
Speed Limit:	

LANE CONFIGURATION:

Lane #	Dir	Informatio	Sensors	Spacing	Loop Leng	Comment
1			Ax-Ax	4.0 ft		
3			Ax-Ax	4.0 ft		

AVERAGE DAILY TRAFFIC (ADT):

	Weekday	%		Weekend	%		Total ADT	%
Cars:	480	57.6	Cars:			Cars:	480	57.6
Trucks:	354	42.4	Trucks:			Trucks:	354	42.4
Total:	834		Total:			Total:	834	

SPEED TOTALS:

50 %:	46.5	mph	Top Speed:	78.1	mph		Avg Truck Speed:	42.4	mph
85 %:	54.7	mph	Low Speed:	4.3	mph	%	Avg Car Speed:	48.3	mph
Avg:	45.8	mph	10mph Pace Speed:	39.4	49.3	46.8			

PEEK HOUR TOTALS:

AM Peak Hour (Volume):			Avg	AM Peak Hour (Speed):			
Weekday:							
Weekend:							
PM Peak Hour (Volume):			Avg	PM Peak Hour (Speed):			
Weekday:	16:15	17:15	48	14:45	15:45	48.5	mph
Weekend:							

GRAND TOTALS:

Total Cars:	80	480	(ADT)	Average Length:	30.1 ft	Average Headway:	87.9 sec
Total Trucks:	59	354	(ADT)	Average Axles:	3.4	Average Gap:	87.4 sec
Total Volume:	139	834					

Per-Vehicle Summary Report: CAMPBELL, MOORE

	CAM-MOO-T
Info Line 1:	Moore
Info Line 2:	
Counter Type:	Apollo
Counter Version:	1.51
Serial #:	11194
Latitude:	
Longitude:	
Lanes:	2
Speed Limit:	

LANE CONFIGURATION:

Lane #	Dir	Informati	Sensors	Spacing	Loop Leng	Comment
1			Ax-Ax	4.0 ft		
3			Ax-Ax	4.0 ft		

AVERAGE DAILY TRAFFIC (ADT):

	Weekday	%		Weekend	%		Total ADT	%
Cars:	48	28.6	Cars:			Cars:	48	28.6
Trucks:	120	71.4	Trucks:			Trucks:	120	71.4
Total:	168		Total:			Total:	168	

SPEED TOTALS:

50 %:	32.6	mph	Top Speed:	39.5	mph			Avg Truck Speed:	33.1	mph
85 %:	37.3	mph	Low Speed:	9.6	mph		%	Avg Car Speed:	30.1	mph
Avg:	32.2	mph	10mph Pace Speed:	30	39.9	81				

PEEK HOUR TOTALS:

AM Peak Hour (Volume):			Avg	AM Peak Hour (Speed):			
Weekday:	8:00	9:00	14	8:15	9:15	33.4	mph
Weekend:							
PM Peak Hour (Volume):			Avg	PM Peak Hour (Speed):			
Weekday:							
Weekend:							

GRAND TOTALS:

Total Cars:	6	48	(ADT)	Average Length:	45.9 ft	Average Headway:	247.3 sec
Total Trucks:	15	120	(ADT)	Average Axles:	4.5	Average Gap:	246.3 sec

Per-Vehicle Summary Report: CAMPBELL, TODD

Station ID : CAM-TOD-U

Last Connected Device Type : Apollo

Info Line 1 :
Info Line 2 :
GPS Lat/Lon :
DB File : CAM-TOD-U.DB

Version Number : 1.66
Serial Number : 11166
Number of Lanes : 2
Posted Speed Limit : 0.0 mph

Lane Configuration

#	Dir.	Information	Vehicle Sensors	Sensor Spac	Loop Length
1.00			Axle-Axle		4.0 ft
3.00			Axle-Axle		4.0 ft

Average Daily Traffic (ADT)

Weekday			Weekend		Total ADT		
Cars :	126	67%	Cars :		Cars :	**126**	67%
Trucks :	60	33%	Trucks :		Trucks :	**60**	33%
Total :	186		Total :		Total :	**186**	

Speed Totals

50 % :	33.1 mph	Top Speed :	100.5 mph		Average Truck Speed :	25.7 mph
85 % :	43.0 mph	Low Speed :	6.0 mph		Average Car Speed :	37.5 mph
Avg :	33.7 mph	10mph Pace Speed:	33.0 - 42.9	37.50%		

Peak Hour Totals

AM Peak Hour (Volume)
Weekday : 07:00 - 08:00 (Avg 15)
Weekend :
PM Peak Hour (Volume)

Weekday :
Weekend :

AM Peak Hour (Speed)
09:30 - 10:30 (100.5 mph)
PM Peak Hour (Speed)

Grand Totals

Total Cars :	22	(	126	ADT)	Average Len	27.9 ft	Average Headway :	294.1 sec
Total Trucks :	10	(	60	ADT)	Average Axl	3.30	Average (	293.3 sec
Total Volume :	32	(	186	ADT)				

Per-Vehicle Summary Report: CAMPBELL, CHRISTENSEN

Station ID : CAM-CHR-U

Last Connected Device Type : Apollo

Info Line 1 :
Info Line 2 :
GPS Lat/Lon :
DB File : CAM-CHR-U.DB

Version Number : 1.66
Serial Number : 11297
Number of Lanes : 2
Posted Speed Limit : 0.0 mph

Lane Configuration

#	Dir.	Information	Vehicle Sensors	Sensor Spacing	Loop Length
1.00			Axle-Axle	4.0 ft	
3.00			Axle-Axle	4.0 ft	

Average Daily Traffic (ADT)

Weekday			Weekend		Total ADT		
Cars :	176	66%	Cars :		Cars :	**176**	66%
Trucks :	88	34%	Trucks :		Trucks :	**88**	34%
Total :	264		Total :		Total :	**264**	

Speed Totals

50 % :	39.5 mph	Top Speed :	48.5 mph		Average Truck Speed :	38.0 mph
85 % :	46.9 mph	Low Speed :	24.5 mph		Average Car Speed :	40.1 mph
Avg :	39.4 mph	10mph Pace Speed:	37.4 - 47.3	66.70%		

Peak Hour Totals

AM Peak Hour (Volume)
Weekday : 08:15 - 09:15 (Avg 16)
Weekend :
PM Peak Hour (Volume)

Weekday :
Weekend :

AM Peak Hour (Speed)
09:45 - 10:45 (42.5 mph)
PM Peak Hour (Speed)

Grand Totals

Total Cars :	22	(	176	ADT)	Average Length :	19.3 ft	Average Headway :	286.0 sec
Total Trucks :	11	(	88	ADT)	Average Axles :	2.60	Average Gap :	285.7 sec
Total Volume :	33	(	264	ADT)				

Per-Vehicle Summary Report: CAMPBELL, HAYDEN

Station ID : CAM-HAY-U

Last Connected Device Type : Apollo

Info Line 1 :
Info Line 2 :
GPS Lat/Lon :
DB File : CAM-HAY-U.DB

Version Number : 1.66
Serial Number : 11166
Number of Lanes : 2
Posted Speed Limit : 0.0 mph

Lane Configuration

#	Dir.	Information	Vehicle Sensors	Sensor Spac	Loop Length
1.00			Axle-Axle		4.0 ft
3.00			Axle-Axle		4.0 ft

Average Daily Traffic (ADT)

	Weekday			Weekend		Total ADT		
Cars :	120	88%	Cars :		Cars :	**120**	88%
Trucks :	16	12%	Trucks :		Trucks :	**16**	12%
Total :	136		Total :		Total :	**136**	

Speed Totals

50 % :	40.2 mph	Top Speed :	43.2 mph		Average Truck Speed :	36.3 mph
85 % :	42.3 mph	Low Speed :	6.3 mph		Average Car Speed :	34.4 mph
Avg :	34.7 mph	10mph Pace Speed:	34.5 - 44.4	76.50%		

Peak Hour Totals

AM Peak Hour (Volume)
Weekday : 07:00 - 08:00 (Avg 12)
Weekend :

AM Peak Hour (Speed)
07:15 - 08:´(40.3 mph)

PM Peak Hour (Volume)
Weekday :
Weekend :

PM Peak Hour (Speed)

Grand Totals

Total Cars :	15	(	120	ADT)	Average Len	14.7 ft	Average Headway :	551.8 sec
Total Trucks :	2	(	16	ADT)	Average Axl	2.40	Average (	551.4 sec
Total Volume :	17	(	136	ADT)				

Per-Vehicle Summary Report: CAMPBELL, BLACK & YELLOW

Station ID : CAM-BLA-U

Last Connected Device Type : Apollo

Info Line 1 :
Info Line 2 :
GPS Lat/Lon :
DB File : CAM-BLA-U.DB

Version Number : 1.66
Serial Number : 11166
Number of Lanes : 2
Posted Speed Limi 0.0 mph

Lane Configuration

#	Dir.	Information	Vehicle Sensors	Sensor Spacing	Loop Length
1.00			Axle-Axle		4.0 ft
3.00			Axle-Axle		4.0 ft

Average Daily Traffic (ADT)

	Weekday			Weekend		Total ADT		
Cars :	320	63%	Cars :		Cars :	**320**	63%
Trucks :	184	37%	Trucks :		Trucks :	**184**	37%
Total :	504		Total :		Total :	**504**	

Speed Totals

50 % :	28.0 mph	Top Speed :	66.7 mph		Average Truck Speed :	25.2 mph
85 % :	42.9 mph	Low Speed :	3.4 mph		Average Car Speed :	29.5 mph
Avg :	28.0 mph	10mph Pace Speed:	23.7 - 33.6	39.10%		

Peak Hour Totals

AM Peak Hour (Volume)
Weekday : 10:30 - 11:30 (Avg 26)
Weekend :

AM Peak Hour (Speed)
10:30 - 11:30 (32.4 mph)

PM Peak Hour (Volume)
Weekday : 12:00 - 13:00 (Avg 24)
Weekend :

PM Peak Hour (Speed)
12:00 - 13:00 (25.0 mph)

Grand Totals

Total Cars :	41	(	320	ADT)	Average Length	22.7 ft	Average Headway :	145.9 sec
Total Trucks :	23	(	184	ADT)	Average Axles :	3.10	Average Gap :	145.1 sec
Total Volume :	64	(	504	ADT)				

Per-Vehicle Summary Report: CAMPBELL, IBERLIN

Station ID : CAM-IBE-U

Last Connected Device Type : Apollo

Info Line 1 :
Info Line 2 :
GPS Lat/Lon :
DB File : CAM-IBE-U.DB

Version Number : 1.66
Serial Number : 11166
Number of Lanes : 2
Posted Speed Limit : 0.0 mph

Lane Configuration

#	Dir.	Information	Vehicle Sensors	Sensor Spaci	Loop Length
1.00			Axle-Axle		4.0 ft
3.00			Axle-Axle		4.0 ft

Average Daily Traffic (ADT)

	Weekday				Weekend		Total ADT		
	Cars :	222	84%		Cars :		Cars :	**222**	84%
Trucks :		42	16%	Trucks :			Trucks :	**42**	16%
	Total :	264			Total :		Total :	**264**	

Speed Totals

50 % :	28.2 mph	Top Speed :	43.9 mph		Average Truck Speed :	18.6 mph
85 % :	40.6 mph	Low Speed :	6.0 mph		Average Car Speed :	31.5 mph
Avg :	29.5 mph	10mph Pace Speed:	24.6 - 34.5	47.70%		

Peak Hour Totals

AM Peak Hour (Volume)			AM Peak Hour (Speed)
Weekday :			
Weekend :			
PM Peak Hour (Volume)			PM Peak Hour (Speed)
Weekday :	13:30 - 14:30	(Avg 20)	12:30 - 1:(33.6 mph)
Weekend :			

Grand Totals

Total Cars :	37	(222	ADT)	Average Leng 16.1 ft	Average Headway :	230.4 sec
Total Trucks :	7	(42	ADT)	Average Axle 2.30	Average (	230.0 sec

Per-Vehicle Summary Report: JOHNSON, TTT

Station ID : JOH-TTT-U

Last Connected Device Type : Apollo

Info Line 1 :
Info Line 2 :
GPS Lat/Lon :
DB File : JOH-TTT-U.DB

Version Number : 1.66
Serial Number : 11297
Number of Lanes : 2
Posted Speed Limit : 0.0 mph

Lane Configuration

#	Dir.	Information	Vehicle Sensors	Sensor Spacing	Loop Length
1.00			Axle-Axle	4.0 ft	
3.00			Axle-Axle	4.0 ft	

Average Daily Traffic (ADT)

	Weekday				Weekend		Total ADT		
	Cars :	120	76%		Cars :		Cars :	**120**	76%
Trucks :		36	24%	Trucks :			Trucks :	**36**	24%
	Total :	156			Total :		Total :	**156**	

Speed Totals

50 % :	25.1 mph	Top Speed :	36.4 mph		Average Truck Speed :	23.8 mph
85 % :	34.4 mph	Low Speed :	10.7 mph		Average Car Speed :	24.5 mph
Avg :	24.4 mph	10mph Pace Speed:	26.9 - 36.8	48.10%		

Peak Hour Totals

AM Peak Hour (Volume)			AM Peak Hour (Speed)	
Weekday :				
Weekend :				
PM Peak Hour (Volume)			PM Peak Hour (Speed)	
Weekday :	13:00 - 14:00	(Avg 14)	12:30 - 13:30	(31.2 mph)
Weekend :				

Grand Totals

Total Cars :	21 (	120 ADT)	Average Length : 32.3 ft		Average Headway :	346.3 sec
Total Trucks :	6 (	36 ADT)	Average Axles :	3.40	Average Gap :	345.3 sec
Total Volume :	27 (	156 ADT)				

Per-Vehicle Summary Report: SWEETWATER, WAMSUTTER

Station ID : SWE-WAM-U

Last Connected Device Type : Apollo

Info Line 1 :
Info Line 2 :
GPS Lat/Lon :
DB File : SWE-WAM-U.DB

Version Number : 1.66
Serial Number : 11297
Number of Lanes : 2
Posted Speed Limi 0.0 mph

Lane Configuration

#	Dir.	Information	Vehicle Sensors	Sensor Spacing	Loop Length
1.00			Axle-Axle		4.0 ft
3.00			Axle-Axle		4.0 ft

Average Daily Traffic (ADT)

	Weekday			Weekend		Total ADT		
Cars :		432	79%	Cars :		Cars :	**432**	79%
Trucks :		114	21%	Trucks :		Trucks :	**114**	21%
Total :		546		Total :		Total :	**546**	

Speed Totals

50 % : 39.5 mph	Top Speed :	55.3 mph		Average Truck Speed :	32.0 mph
85 % : 45.5 mph	Low Speed :	9.9 mph		Average Car Speed :	40.0 mph
Avg : 38.3 mph	10mph Pace Speed:	34.6 - 44.5	60.40%		

Peak Hour Totals

AM Peak Hour (Volume)
Weekday : 01:30 - 02:30 (Avg 39)
Weekend :

AM Peak Hour (Speed)
04:00 - 05:00 (40.8 mph)

PM Peak Hour (Volume)
Weekday :
Weekend :

PM Peak Hour (Speed)

Grand Totals

Total Cars :	72 (	432 ADT)	Average Length : 21.4 ft	Average Headway : 108.5 sec
Total Trucks :	19 (	114 ADT)	Average Axles : 2.70	Average (108.0 sec
Total Volume :	91 (	546 ADT)		

Per-Vehicle Summary Report: SWEETWATER, PATRICK DRAW

Station ID : SWE-PAT-U

Last Connected Device Type : Apollo

Info Line 1 :
Info Line 2 :
GPS Lat/Lon :
DB File : SWE-PAT-U.DB

Version Number : 1.66
Serial Number : 11166
Number of Lanes : 2
Posted Speed Limit : 0.0 mph

Lane Configuration

#	Dir.	Information	Vehicle Sensors	Sensor Spacing	Loop Length
1.00			Axle-Axle	4.0 ft	
3.00			Axle-Axle	4.0 ft	

Average Daily Traffic (ADT)

	Weekday			Weekend	Total ADT		
Cars :		144	81%	Cars :	Cars :	**144**	81%
Trucks :		32	19%	Trucks :	Trucks :	**32**	19%
Total :		176		Total :	Total :	**176**	

Speed Totals

50 % : 28.1 mph	Top Speed :	43.2 mph		Average Truck Speed :	22.3 mph
85 % : 38.0 mph	Low Speed :	12.2 mph		Average Car Speed :	28.6 mph
Avg : 27.5 mph	10mph Pace Speed:	24.6 - 34.5	47.80%		

Peak Hour Totals

AM Peak Hour (Volume)
Weekday : 11:00 - 12:00 (Avg 6)
Weekend :

AM Peak Hour (Speed)
10:45 - 11:45 (36.8 mph)

PM Peak Hour (Volume)
Weekday : 12:15 - 13:15 (Avg 15)
Weekend :

PM Peak Hour (Speed)
12:30 - 13:30 (31.0 mph)

Grand Totals

Total Cars :	19 (	144 ADT)	Average Length : 14.6 ft	Average Headway : 291.4 sec
Total Trucks :	4 (	32 ADT)	Average Axles : 2.10	Average Gap : 291.0 sec
Total Volume :	23 (	176 ADT)		

Per-Vehicle Summary Report: WESTON, GRIEVES

Station ID : WES-GRI-U

Last Connected Device Type Apollo

Info Line 1 :
Info Line 2 :
GPS Lat/Lon :
DB File : WES-GRI-U.DB

Version Number : 1.66
Serial Number : 11166
Number of Lanes : 2
Posted Speed Limit : 0.0 mph

Lane Configuration

#	Dir.	Information	Vehicle Sensors	Sensor Spacing	Loop Length
1.00			Axle-Axle	4.0 ft	
3.00			Axle-Axle	4.0 ft	

Average Daily Traffic (ADT)

	Weekday			Weekend	Total ADT	
Cars :	126	80%	Cars :		Cars : **126**	80%
Trucks :	30	20%	Trucks :		Trucks : **30**	20%
Total :	156		Total :		Total : **156**	

Speed Totals

50 % : 39.0 mph | Top Speed : 55.9 mph | Average Truck Speed : 41.4 mph
85 % : 45.7 mph | Low Speed : 13.7 mph | Average Car Speed : 37.0 mph
Avg : 37.9 mph | 10mph Pace Speed: 35.8 - 45.7 61.50%

Peak Hour Totals

AM Peak Hour (Volume) | AM Peak Hour (Speed)
Weekday : 11:00 - 12:00 (Avg 12) | 10:45 - 11:45 (38.4 mph)
Weekend :
PM Peak Hour (Volume) | PM Peak Hour (Speed)

Weekday : 13:45 - 14:45 (Avg 12) | 12:15 - 13:15 (47.5 mph)
Weekend :

Grand Totals

Total Cars :	21 (126 ADT)	Average Length 18.6 ft	Average Headway : 402.3 sec
Total Trucks :	5 (30 ADT)	Average Axles 2.50	Average Gap : 402.0 sec
Total Volume :	26 (156 ADT)		

Per-Vehicle Summary Report: WESTON, BRUCE

Station ID : WES-BRU-U

Last Connected Device Type : Apollo

Info Line 1 :
Info Line 2 :
GPS Lat/Lon :
DB File : WES-BRU-U.DB

Version Number : 1.66
Serial Number : 11297
Number of Lanes : 2
Posted Speed Limi 0.0 mph

Lane Configuration

#	Dir.	Information	Vehicle Sensors	Sensor Spacing	Loop Length
1.00			Axle-Axle	4.0 ft	
3.00			Axle-Axle	4.0 ft	

Average Daily Traffic (ADT)

	Weekday		Weekend	Total ADT	
Cars :	84	93%	Cars :	Cars : **84**	93%
Trucks :	6	7%	Trucks :	Trucks : **6**	7%
Total :	90		Total :	Total : **90**	

Speed Totals

50 % : 36.0 mph | Top Speed : 51.3 mph | Average Truck Speed : 8.6 mph
85 % : 41.8 mph | Low Speed : 8.6 mph | Average Car Speed : 34.0 mph
Avg : 32.3 mph | 10mph Pace Speed: 35.9 - 45.8 60.00%

Peak Hour Totals

AM Peak Hour (Volume) | AM Peak Hour (Speed)
Weekday : 07:45 - 08:45 (Avg 8) | 07:00 - 08:00 (42.8 mph)
Weekend :
PM Peak Hour (Volume) | PM Peak Hour (Speed)

Weekday :
Weekend :

Grand Totals

Total Cars :	14 (84 ADT)	Average Length : 13.2 ft	Average Headway : 568.9 sec
Total Trucks :	1 (6 ADT)	Average Axles : 2.20	Average Gap : 568.5 sec
Total Volume :	15 (90 ADT)		

Per-Vehicle Summary Report: WESTON, MUSH CREEK

Station ID : WES-MUS-U

Last Connected Device Type Apollo

Info Line 1 :		Version Number :	1.66
Info Line 2 :		Serial Number :	11166
GPS Lat/Lon :		Number of Lanes :	2
DB File :	WES-MUS-U.DB	Posted Speed Limi	0.0 mph

Lane Configuration

#	*Dir.*	*Information*	*Vehicle Sensors*	*Sensor Spacing*	*Loop Length*
1.00			Axle-Axle	4.0 ft	
3.00			Axle-Axle	4.0 ft	

Average Daily Traffic (ADT)

Weekday				Weekend	**Total ADT**		
Cars :	180	99%		Cars :	Cars :	**180**	99%
Trucks :	0		1%	Trucks :	Trucks :	**0**	1%
Total :	180			Total :	Total :	**180**	

Speed Totals

50 % :	22.1 mph	Top Speed :	32.2 mph		Average Truck Speed :	
85 % :	25.7 mph	Low Speed :	11.7 mph		Average Car Speed :	22.9 mph
Avg :	22.9 mph	10mph Pace Speed:	19.7 - 29.6	73.30%		

Peak Hour Totals

AM Peak Hour (Volume)			AM Peak Hour (Speed)	
Weekday :				
Weekend :				
PM Peak Hour (Volume)			PM Peak Hour (Speed)	
Weekday :	19:30 - 20:30	(Avg 14)	17:15 - 18:15	(27.5 mph)
Weekend :				

Grand Totals

Total Cars :	15 (	180 ADT)	Average Length :	13.6 ft	Average Headway :	456.3 sec
Total Trucks :	0 (	0 ADT)	Average Axles :	2.30	Average Gap	456.0 sec
Total Volume :	15 (	180 ADT)				

APPENDIX E: CMAQ ROADS – SOIL PROPERTIES

Soil properties

County:	Lincoln		
Road	**Muddy Creek**	**Gomer**	**Sublett-Pomeroy**
Sieve Size	Percent Passing		
1"	100%	100%	100%
3/4"	99%	100%	99%
1/2"	97%	91%	87%
3/8"	93%	84%	78%
#4	87%	63%	54%
#8	81%	43%	39%
#10	79%	42%	37%
#30	51%	27%	23%
#40	49%	26%	22%
#100	-	17%	13%
#200	19.4%	12.5%	8.9%
Liquid Limit, LL	18.8	18.76	16.64
Plastic Limit, PL	15.38	0	12.12
Plastic Index (LL-PL)	3.42	18.76	4.52
AASHTO Classification	A-1-b	A-2-6	A-1-a

County:	Converse	
Road	**Jenne Trail**	**Ross**
Sieve Size	Percent Passing	
1"	100%	89%
3/4"	96%	84%
1/2"	85%	73%
3/8"	78%	70%
#4	60%	63%
#8	53%	59%
#10	51%	57%
#30	35%	40%
#40	34%	37%
#100	-	14%
#200	14.1%	10.8%
Liquid Limit, LL	17.97	17
Plastic Limit, PL	13.33	13.33
Plastic Index (LL-PL)	4.64	3.67
AASHTO Classification	A-1-b	A-1-b

County:	Johnson
Road	**TTT**
Sieve Size	Percent Passing
1"	100%
3/4"	99%
1/2"	91%
3/8"	83%
#4	64%
#8	49%
#10	47%
#30	28%
#40	26%
#100	12%
#200	8.3%
Liquid Limit, LL	15.63
Plastic Limit, PL	0
Plastic Index (LL-PL)	15.63
AASHTO Classification	A-2-6

County:	Crook
Road	**D-Road**
Sieve Size	Percent Passing
1"	100%
3/4"	99%
1/2"	88%
3/8"	78%
#4	56%
#8	44%
#10	43%
#30	31%
#40	30%
#100	-
#200	14.5%
Liquid Limit, LL	25.97
Plastic Limit, PL	20
Plastic Index (LL-PL)	5.97
AASHTO Classification	A-1-a

County: **Sweetwater**

Road	**Wamsutter**	**Patrick Draw**
Sieve Size	Percent Passing	
1"	93%	80%
3/4"	89%	71%
1/2"	76%	59%
3/8"	67%	51%
#4	49%	34%
#8	37%	30%
#10	36%	30%
#30	26%	26%
#40	24%	25%
#100	16%	18%
#200	10.5%	13.4%
Liquid Limit, LL	19.67	23.53
Plastic Limit, PL	12.5	17.65
Plastic Index (LL-PL)	7.17	5.88
AASHTO Classification	A-2-4	A-1

County: **Weston**

Road	**Grieves**	**Bruce**	**Mush Creek**
Sieve Size	Percent Passing		
1"	100%	100%	100%
3/4"	100%	99%	99%
1/2"	99%	97%	93%
3/8"	94%	91%	84%
#4	69%	60%	60%
#8	46%	37%	47%
#10	43%	36%	45%
#30	22%	23%	28%
#40	21%	22%	27%
#100	12%	15%	19%
#200	8.1%	11.0%	14.9%
Liquid Limit, LL	13.34	15.69	15.02
Plastic Limit, PL	0	9.38	9.09
Plastic Index (LL-PL)	13.34	6.31	5.93
AASHTO Classification	A-2-6	A-2-4	A-1-a

County:	**Campbell**								
Road	**Cosner**	**Clarkelen**	**Moore**	**Turnercrest**	**Todd**	**Christensen**	**Hayden**	**Black & Yellow**	**Iberlin**
Sieve Size	Percent Passing								
1"	99%	100%	95%	100%	100%	100%	99%	97%	100%
3/4"	99%	100%	86%	98%	97%	98%	96%	93%	99%
1/2"	93%	67%	70%	85%	80%	91%	84%	82%	95%
3/8"	88%	48%	62%	77%	69%	84%	76%	73%	90%
#4	72%	30%	44%	59%	51%	66%	59%	57%	72%
#8	63%	24%	37%	50%	40%	54%	34%	46%	56%
#10	61%	24%	36%	48%	39%	52%	33%	45%	54%
#30	45%	18%	25%	26%	28%	33%	24%	33%	33%
#40	43%	18%	24%	24%	26%	30%	22%	30%	30%
#100	-	-	-	12%	16%	15%	9%	15%	14%
#200	11.6%	5.1%	10.2%	8.1%	11.3%	10.5%	5.9%	11.1%	9.6%
Liquid Limit, LL	17.56	15.14	21.5	17.2	19.67	19.45	15.85	14.06	16.22
Plastic Limit, PL	0	0	0	0	12.5		0	0	11.11
Plastic Index (LL-PL)	17.56	15.14	21.5	17.2	7.17	19.45	15.85	14.06	5.11
AASHTO Classification	A-2-6	A-2-6	A-2-6	A-2-6	A-2-4	A-2-6	A-2-6	A-2-6	A-1-b

Moisture Content

County	Road	Moisture Content Before Treatment	Moisture Content After Treatment
Lincoln	Muddy Creek	1.62%	7.21%
	Gomer	2.83%	TBT
	Sublett-Pomeroy Basin	1.41%	TBT
Converse	Jenne Trail	4.01%	2.68%
	Ross Road	2.07%	TBT
Crook	D-Road	2.25%	1.59%
Campbell	Cosner	2.10%	3.18%
	Clarkelen	0.28%	1.54%
	Moore	0.41%	1.65%
	Turnercrest	1.49%	TBT
	Todd	1.27%	TBT
	Christensen	2.91%	TBT
	Hayden	1.12%	TBT
	Black & Yellow	1.91%	TBT
	Iberlin	2.35%	TBT
Johnson	TTT Road	0.99%	TBT
Sweetwater	Wamsutter S	3.18%	TBT
	Patrick Draw	6.12%	TBT
Weston	Grieves	0.44%	TBT
	Bruce	0.70%	TBT
	Mush Creek	0.53%	TBT

APPENDIX F: CMAQ ROADS – REGRESSION ANALYSIS

EPAM-5000 Regression Model

Road	Average EPAM Concentration (mg/m^3)	Percent Fines (%)	Liquid Limit	Plasticity Index	Moisture Content (%)	Trucks	ADT	Average Speed (mph)
1	2.227	19.4	18.8	3.4	1.62	13.0	95	35.2
2	0.973	12.5	15.8	15.8	2.83	0.0	80	40.5
3	0.927	8.9	16.6	4.5	1.41	7.0	120	38.8
4	2.674	14.1	18.0	4.6	4.01	45.0	536	43.5
5	0.914	10.8	17.0	3.7	2.07	37.0	592	38.2
6	1.779	14.5	26.0	6.0	2.25	16.0	384	62.1
7	1.846	11.6	17.6	17.6	2.10	42.4	834	54.7
8	1.433	5.1	15.1	15.1	0.28	62.5	672	47.8
9	3.043	10.2	21.5	21.5	0.41	71.4	168	37.3
10	2.017	8.1	13.2	13.2	1.49	13.0	288	43.6
11	1.287	11.3	16.7	4.8	1.27	33.0	186	43.0
12	3.010	10.5	19.5	19.5	2.91	34.0	264	46.9
13	1.870	5.9	15.9	15.9	1.12	12.0	136	42.3
14	1.471	11.1	14.1	14.1	1.91	37.0	504	42.9
15	4.036	9.6	16.2	5.1	2.35	16.0	264	40.6
16	2.166	8.3	15.6	15.6	0.99	24.0	156	34.4
17	1.330	10.5	16.7	4.8	3.18	21.0	546	45.5
18	1.673	13.4	23.5	5.9	6.12	19.0	176	38.0
19	2.383	8.1	13.3	13.3	0.44	20.0	156	45.7
20	1.270	11.0	15.7	6.3	0.70	7.0	90	41.8
21	2.371	14.9	15.0	5.9	0.53	0.0	180	25.7

```
> input=read.table("EPAM.alldata.txt",header=T,sep='')  #Define dataset

> EPAM=input$EPAM

> Fines=input$Fines

> LL=input$LL

> PI=input$PI

> Moisture=input$Moisture

> Trucks=input$Trucks

> ADT=input$ADT

> Speed=input$Speed  #Define Variables

> model=lm(EPAM~Fines+LL+PI+Moisture+Trucks+ADT+Speed)

> rr = rstudent(model)

> yh = predict(model)     # see predicted values
```

```
> cbind(EPAM,yh,rr)       #create table from EPAM, predicted, and residuals

    EPAM       yh           rr
1  2.227 2.182039  0.06720525
2  0.973 2.081523 -1.64400857
3  0.927 1.651597 -0.90372944
4  2.674 2.031429  0.91327980
5  0.914 1.654240 -0.99229014
6  1.779 1.669346  0.27987817
7  1.846 1.783914  0.09600283
8  1.433 1.859509 -0.59033912
9  3.043 2.904456  0.28277668
10 2.017 1.736432  0.32845768
11 1.287 2.018422 -0.98454673
12 3.010 2.324669  0.86683295
13 1.870 1.839279  0.03841888
14 1.471 2.000918 -0.64489749
15 4.036 1.699178  4.14590222
16 2.166 2.103077  0.07423260
17 1.330 1.513851 -0.21838421
18 1.673 2.146536 -0.89165010
19 2.383 1.919680  0.59111347
20 1.270 1.776051 -0.60370491
21 2.371 1.803855  1.00513005

> input=input[-15,]       # remove outlier based on residuals

######################################################################
```

```
> model=lm(EPAM~Fines+LL+PI+Moisture+Trucks+ADT+Speed) #Create linear model
with EPAM as response variable

> rr = rstudent(model)

> yh = predict(model)     # see predicted values

> cbind(EPAM,yh,rr)       #create table from EPAM, predicted, and residuals

    EPAM       yh          rr

1  2.227 2.252882 -0.05781133

2  0.973 2.085556 -3.00241026
3  0.927 1.237272 -0.57785979
4  2.674 1.825345  2.06264574
5  0.914 1.371032 -0.92148555
6  1.779 1.676080  0.39373066
7  1.846 2.007200 -0.37765558
8  1.433 1.718153 -0.59170573
9  3.043 3.133598 -0.28053230
10 2.017 1.538385  0.86398462
11 1.287 1.743792 -0.92519369
12 3.010 2.395743  1.19714303
13 1.870 1.622672  0.46886199
14 1.471 2.000452 -0.98685287
15 2.166 1.997874  0.29761850
16 1.330 1.183030  0.26387155
17 1.673 1.808540 -0.38190787
18 2.383 1.750132  1.27774210
19 1.270 1.542330 -0.48560982
20 2.371 1.773933  1.70696465

> input=input[-2,]   # remove outlier

> model=lm(EPAM~Fines+LL+PI+Moisture+Trucks+ADT+Speed)

####################################################################
```

```
> step(model)           #best fit model using AIC

Start:  AIC=-22.97
EPAM ~ Fines + LL + PI + Moisture + Trucks + ADT + Speed


           Df Sum of Sq    RSS     AIC

- Speed     1   0.00594 2.4494 -24.923
- LL        1   0.09573 2.5392 -24.239
- Moisture  1   0.13410 2.5776 -23.954
- Trucks    1   0.14802 2.5915 -23.852
<none>                  2.4435 -22.970
- ADT       1   0.42562 2.8691 -21.919
- Fines     1   1.61112 4.0546 -15.347
- PI        1   2.56350 5.0070 -11.339


Step:  AIC=-24.92
EPAM ~ Fines + LL + PI + Moisture + Trucks + ADT


           Df Sum of Sq    RSS     AIC

- LL        1   0.10863 2.5580 -26.099
- Moisture  1   0.12822 2.5776 -25.954
- Trucks    1   0.14952 2.5989 -25.797
<none>                  2.4494 -24.923
- ADT       1   0.63639 3.0858 -22.535
- Fines     1   1.77305 4.2225 -16.576
- PI        1   2.67018 5.1196 -12.916


Step:  AIC=-26.1
EPAM ~ Fines + PI + Moisture + Trucks + ADT

           Df Sum of Sq    RSS     AIC

- Moisture  1   0.05012 2.6081 -27.730
- Trucks    1   0.08683 2.6449 -27.465
<none>                  2.5580 -26.099
```

```
- ADT       1   0.53676 3.0948 -24.480
- Fines     1   1.73001 4.2880 -18.284

- PI        1   2.58658 5.1446 -14.823



Step:  AIC=-27.73


EPAM ~ Fines + PI + Trucks + ADT


         Df Sum of Sq    RSS     AIC


- Trucks  1   0.08564 2.6938 -29.116
<none>                2.6081 -27.730
- ADT     1   0.48998 3.0981 -26.459
- Fines   1   2.04552 4.6537 -18.729
- PI      1   2.53647 5.1446 -16.823



Step:  AIC=-29.12


EPAM ~ Fines + PI + ADT


        Df Sum of Sq    RSS     AIC


<none>               2.6938 -29.116
- ADT    1    0.4172 3.1110 -28.380
- Fines  1    2.1422 4.8360 -19.999
- PI     1    4.0339 6.7276 -13.726


Call:
lm(formula = EPAM ~ Fines + PI + ADT)

Coefficients:


(Intercept)        Fines           PI          ADT


 -0.1938913    0.1221526    0.0926890   -0.0006798


###################################################################
```

```
> step(model,k=log(length(EPAM))) #best fit model using BIC

Start:  AIC=-15.41

EPAM ~ Fines + LL + PI + Moisture + Trucks + ADT + Speed



           Df Sum of Sq    RSS      AIC
- Speed     1   0.00594 2.4494 -18.3123
- LL        1   0.09573 2.5392 -17.6283
- Moisture  1   0.13410 2.5776 -17.3433
- Trucks    1   0.14802 2.5915 -17.2409
<none>                  2.4435 -15.4140
- ADT       1   0.42562 2.8691 -15.3075
- Fines     1   1.61112 4.0546  -8.7362
- PI        1   2.56350 5.0070  -4.7275



Step:  AIC=-18.31

EPAM ~ Fines + LL + PI + Moisture + Trucks + ADT

           Df Sum of Sq    RSS      AIC


- LL        1   0.10863 2.5580 -20.4323
- Moisture  1   0.12822 2.5776 -20.2872
- Trucks    1   0.14952 2.5989 -20.1309
<none>                  2.4494 -18.3123
- ADT       1   0.63639 3.0858 -16.8684
- Fines     1   1.77305 4.2225 -10.9098
- PI        1   2.67018 5.1196  -7.2493



Step:  AIC=-20.43

EPAM ~ Fines + PI + Moisture + Trucks + ADT

           Df Sum of Sq    RSS     AIC
```

```
- Moisture  1   0.05012 2.6081 -23.008
- Trucks    1   0.08683 2.6449 -22.742
<none>                  2.5580 -20.432
- ADT       1   0.53676 3.0948 -19.758
- Fines     1   1.73001 4.2880 -13.561
- PI        1   2.58658 5.1446 -10.101


Step:  AIC=-23.01

EPAM ~ Fines + PI + Trucks + ADT

         Df Sum of Sq    RSS     AIC

- Trucks  1   0.08564 2.6938 -25.339
<none>                2.6081 -23.008
- ADT     1   0.48998 3.0981 -22.681
- Fines   1   2.04552 4.6537 -14.951
- PI      1   2.53647 5.1446 -13.046


Step:  AIC=-25.34

EPAM ~ Fines + PI + ADT

        Df Sum of Sq    RSS     AIC

- ADT    1    0.4172 3.1110 -25.547
<none>               2.6938 -25.339
- Fines  1    2.1422 4.8360 -17.166
- PI     1    4.0339 6.7276 -10.893


Step:  AIC=-25.55

EPAM ~ Fines + PI
```

```
        Df Sum of Sq    RSS     AIC

<none>               3.1110 -25.547
- Fines  1    2.2434 5.3545 -18.175
- PI     1    3.8968 7.0078 -13.062

Call:
lm(formula = EPAM ~ Fines + PI)

Coefficients:

(Intercept)        Fines           PI

   -0.42306      0.12485      0.09094

#########################################################################

> model=lm(EPAM~Fines+PI+ADT)     #Best fit model based on AIC
> summary(model)

Call:

lm(formula = EPAM ~ Fines + PI + ADT)

Residuals:

     Min       1Q   Median       3Q      Max

-0.65528 -0.20866 -0.03811  0.18066  1.08356

Coefficients:
```

```
               Estimate Std. Error t value Pr(>|t|)

(Intercept) -0.1938913  0.5531871  -0.350 0.730838
Fines        0.1221526  0.0353680   3.454 0.003544 **
PI           0.0926890  0.0195570   4.739 0.000263 ***
ADT         -0.0006798  0.0004460  -1.524 0.148251

---

Residual standard error: 0.4238 on 15 degrees of freedom

Multiple R-squared:  0.6292,    Adjusted R-squared:  0.555

F-statistic: 8.483 on 3 and 15 DF,  p-value: 0.001561

########################################################################

> model=lm(EPAM~Fines+PI)     #Best fit model based on BIC

> summary(model)

Call:

lm(formula = EPAM ~ Fines + PI)

Residuals:

     Min       1Q   Median       3Q      Max

-0.77982 -0.16214 -0.08124  0.23280  0.91833

Coefficients:
          Estimate Std. Error t value Pr(>|t|)

(Intercept) -0.42306    0.55394  -0.764 0.456147
Fines        0.12485    0.03676   3.397 0.003685 **
```

```
PI           0.09094    0.02031   4.477 0.000381 ***
---

Residual standard error: 0.441 on 16 degrees of freedom

Multiple R-squared:  0.5717,    Adjusted R-squared:  0.5182

F-statistic: 10.68 on 2 and 16 DF,  p-value: 0.001132
```

CSU Dustometer Regression Model

Road	Dustometer Concentration (g/mi)	Percent Fines (%)	Liquid Limit	Plasticity Index	Moisture Content (%)	Trucks	ADT	Average Speed (mph)
1	2.5	19.4	18.8	3.4	1.62	13.0	95	35.2
2	1.4	12.5	15.8	15.8	2.83	0.0	80	40.5
3	1.6	8.9	16.6	4.5	1.41	7.0	120	38.8
4	1.8	14.1	18.0	4.6	4.01	45.0	536	43.5
5	0.7	10.8	17.0	3.7	2.07	37.0	592	38.2
6	4.0	11.6	17.6	17.6	2.10	42.4	834	54.7
7	0.9	8.1	13.2	13.2	1.49	13.0	288	43.6
8	0.8	11.3	16.7	4.8	1.27	33.0	186	43.0
9	1.7	10.5	19.5	19.5	2.91	34.0	264	46.9
10	2.2	5.9	15.9	15.9	1.12	12.0	136	42.3
11	1.0	11.1	14.1	14.1	1.91	37.0	504	42.9
12	0.8	9.6	16.22	5.11	2.35	16.0	264	40.6
13	1.6	8.3	15.6	15.6	0.99	24.0	156	34.4
14	4.0	10.5	16.7	4.8	3.18	21.0	546	45.5
15	1.4	13.4	23.5	5.9	6.12	19.0	176	38.0
16	2.4	8.1	13.3	13.3	0.44	20.0	156	45.7
17	2.5	11.0	15.7	6.3	0.70	7.0	90	41.8
18	2.5	14.9	15.0	5.9	0.53	0.0	180	25.7

```
input=read.table("Dustometer.alldata.txt",header=T,sep='')  #Define dataset
Fines=input$Fines
LL=input$L
PI=input$PI
Moisture=input$Moisture
Trucks=input$Trucks
ADT=input$ADT
Speed=input$Speed
Dustometer=input$Dustometer #Define Variables

model=lm(Dustometer~Fines+PI+Moisture+Trucks+ADT+Speed) #create model without
LL (Collinearity)



rr = rstandard(model)   #get residuals
rr = rstudent(model)     #get residuals
yh = predict(model)     # see predicted values
cbind(Dustometer,yh,rr)       #create table from EPAM, predicted, and
residuals



   Dustometer        yh          rr
```

```
1          2.5 2.3454645  0.25868709
2          1.4 2.4404470 -1.58702524
3          1.6 1.6428345 -0.05043116
4          1.8 1.6019855  0.25128162
5          0.7 1.5638565 -1.22177892
6          4.0 3.5764318  0.76899376
7          0.9 2.1994510 -1.64575933
8          0.8 1.2361182 -0.59813102
9          1.7 1.5729345  0.16585751
10         2.2 1.5341422  0.82506778
11         1.0 1.9143405 -1.11532010
12         0.8 1.7007320 -1.06448980
13         1.6 0.7130326  1.36866897
14         4.0 2.6043528  2.18806184
15         1.4 1.0579215  0.62126298
16         2.4 1.8256947  0.69813513
17         2.5 2.2116035  0.34913161
18         2.5 2.0586565  0.78600890

input=input[-14,]       # remove outlier

################################################################
step(model,k=2) #AIC Model

Start:  AIC=-2.51

Dustometer ~ Fines + PI + Moisture + Trucks + ADT + Speed


           Df Sum of Sq    RSS     AIC

- ADT       1   0.48579 6.9223 -3.2739

- PI        1   0.70485 7.1414 -2.7443

<none>                  6.4365 -2.5108
```

```
- Trucks    1   0.84648 7.2830 -2.4104
- Speed     1   0.97083 7.4073 -2.1226
- Moisture  1   1.22711 7.6636 -1.5444
- Fines     1   2.81636 9.2529  1.6593

Step:  AIC=-3.27
Dustometer ~ Fines + PI + Moisture + Trucks + Speed

           Df Sum of Sq     RSS     AIC
- Trucks    1    0.3699  7.2922 -4.3889
- PI        1    0.7326  7.6549 -3.5637
<none>                   6.9223 -3.2739
- Speed     1    1.2639  8.1862 -2.4231
- Moisture  1    1.3571  8.2794 -2.2305
- Fines     1    3.2522 10.1745  1.2734

Step:  AIC=-4.39
Dustometer ~ Fines + PI + Moisture + Speed

           Df Sum of Sq     RSS     AIC
- PI        1   0.86619  8.1584 -4.4808
- Speed     1   0.89403  8.1862 -4.4229
<none>                   7.2922 -4.3889
- Moisture  1   1.69614  8.9883 -2.8338
- Fines     1   3.04778 10.3400 -0.4523

Step:  AIC=-4.48
Dustometer ~ Fines + Moisture + Speed
```

```
           Df Sum of Sq     RSS     AIC
<none>                   8.1584 -4.4808
- Moisture  1    1.8799 10.0383 -2.9557
- Speed     1    2.0904 10.2488 -2.6028
- Fines     1    2.3412 10.4996 -2.1919

Call:
lm(formula = Dustometer ~ Fines + Moisture + Speed)

Coefficients:
(Intercept)        Fines     Moisture        Speed
   -1.93826      0.13893     -0.26388      0.06519

#################################################################
> step(model,k=log(length(Dustometer)))   #Best BIC Model
Start:  AIC=3.32
Dustometer ~ Fines + PI + Moisture + Trucks + ADT + Speed

           Df Sum of Sq    RSS    AIC
- ADT       1   0.48579 6.9223 1.7254
- PI        1   0.70485 7.1414 2.2550
- Trucks    1   0.84648 7.2830 2.5889
- Speed     1   0.97083 7.4073 2.8767
<none>                  6.4365 3.3217
- Moisture  1   1.22711 7.6636 3.4549
- Fines     1   2.81636 9.2529 6.6586

Step:  AIC=1.73
Dustometer ~ Fines + PI + Moisture + Trucks + Speed
```

```
           Df Sum of Sq     RSS     AIC
- Trucks    1    0.3699  7.2922 -0.2229
- PI        1    0.7326  7.6549  0.6024
<none>                   6.9223  1.7254
- Speed     1    1.2639  8.1862  1.7430
- Moisture  1    1.3571  8.2794  1.9356
- Fines     1    3.2522 10.1745  5.4394

Step:  AIC=-0.22
Dustometer ~ Fines + PI + Moisture + Speed

           Df Sum of Sq     RSS      AIC
- PI        1   0.86619  8.1584 -1.14797
- Speed     1   0.89403  8.1862 -1.09006
<none>                   7.2922 -0.22286
- Moisture  1   1.69614  8.9883  0.49901
- Fines     1   3.04778 10.3400  2.88054

Step:  AIC=-1.15
Dustometer ~ Fines + Moisture + Speed

           Df Sum of Sq     RSS      AIC
<none>                   8.1584 -1.14797
- Moisture  1    1.8799 10.0383 -0.45607
- Speed     1    2.0904 10.2488 -0.10321
- Fines     1    2.3412 10.4996  0.30775
```

```
Call:
lm(formula = Dustometer ~ Fines + Moisture + Speed)

Coefficients:
(Intercept)        Fines     Moisture        Speed
   -1.93826      0.13893     -0.26388      0.06519

> #### AIC and BIC agree on best fit model #####

> model=lm(Dustometer~Fines+Moisture+Speed) # best fit model
> summary(model)

Call:
lm(formula = Dustometer ~ Fines + Moisture + Speed)

Residuals:
     Min       1Q   Median       3Q      Max
-1.29974 -0.62212  0.00221  0.40381  1.31380

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept) -1.93826    1.85562  -1.045   0.3153
Fines        0.13893    0.07193   1.931   0.0755 .
Moisture    -0.26388    0.15246  -1.731   0.1071
Speed        0.06519    0.03572   1.825   0.0910 .
---
Residual standard error: 0.7922 on 13 degrees of freedom
Multiple R-squared:  0.3122,    Adjusted R-squared:  0.1535
F-statistic: 1.967 on 3 and 13 DF,  p-value: 0.1688
```