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CONTROLLING DUST ON UNPAVED ROADS IN THAILAND

An Interactive Qualifying Project Report

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by

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Abstract

This project is intended to contribute to the process of reducing air pollution in Bangkok, Thailand. Specifically, its purpose is to recommend dust suppression agents that can be applied to unpaved roads created for construction projects; but suggestions are made for unpaved roads in all of Thailand as well. The suitability of potential agents is determined by dust suppression ability, cost effectiveness, environmental impact, and feasibility of use in Thailand.

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The organization and content of this report was a collaborative effort between Kevin King, Brian Hagglund, and Jonathan Tripp, with the assistance of Professor Richard Vaz. All members of the project team contributed equally to the completion of this project.

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Executive Summary

High levels of suspended particulate matter exist in Bangkok and throughout the rest of Thailand; much of this is due to dust from unpaved roads. Currently, contractors use water to suppress dust in some areas, but most of Thailand's 10,000 kilometers of unpaved roads receive no treatment whatsoever. Water has been proven to be ineffective, and its availability is limited at times during the year. Chemical and natural dust suppressants represent potentially cost efficient and readily available alternatives to water.

A dust control agent's suitability is determined by its effectiveness, availability, cost, and environmental impact. While considering these factors one must keep in mind climatic conditions and seasonal changes. After potential agents are identified, analysis is required in each of these areas.

Three categories of effective suppressants for unpaved roads have been documented: salts, by-products, and emulsions. The salts include calcium and magnesium chloride. By-products range from lignin sulfonate, soybean oil by-product, and sugar beet extract to distillery waste. Polyvinyl acrylic and petroleum based emulsions comprise the materials in the emulsions group.

Salts work hygroscopically and are available in Thailand. The hygroscopic nature of salts means that they draw moisture from the atmosphere, wetting the particles in the road. Environmentally speaking, chloride is not good in high doses, but runoff levels from treated roads are unlikely to amount to significant quantities. Currently, both of these salts are imported into Thailand, but a large amount of magnesium chloride may be domestically available starting in 2003 from mines in Bamnet Narong.

The by-products suppress dust in different ways, and the availability of some of them is limited. Lignin sulfonate and soybean oil by-product stick road materials together to weigh loose material down; neither product is known, at present, to be available in quantities to cover a significant amount of unpaved road. Sugar beet extract works hygroscopically, like salts, due its large concentration of potassium chloride, but sugar beets do not grow well in the hot climate of Thailand. Insufficient information exists on the use of distillery waste, although stories have surfaced about its effective application as a dust suppressant; Thailand's distilleries have a large amount of this spent wash liquor readily available.

Emulsions are mixtures of water and a given substance; they work as dust suppressants in different ways. The polyvinyl acrylic emulsions form a coat on the surface of a road, retarding loose material from becoming airborne; blending of this material occurs in Chonburi, Thailand. Emulsified asphalt penetrates into the road, adhering to the road particles, and should be available from Thailand's refineries.

To add to the background information researched in the United States and Thailand, availability, cost, and other detailed information was obtained mainly through interviews with experts in Thailand. Suppliers of raw materials, contractors, health specialists, environmental consultants, and people familiar with dust suppressants entertained our questions concerning their specific field of expertise. Parts of the interviews were translated into Thai with the help of Dr. Supawan Tantayanon, our liaison, to accurately convey our thoughts to these individuals.

Some of these individuals attended a roundtable discussion concerning the use of dust suppressants on unpaved roads. In this discussion, we presented our updated findings as a part of an ongoing project concerning air pollution sponsored by the Pollution Control Department (PCD). This meeting provided feedback relating to our findings, discussion on manufacturing practices in Thailand, and information from generally informed and concerned parties.

In addition to information gathered through interviews and discussions, we gained data from students in the Soil Mechanics Laboratory at Chulalongkorn University in Bangkok. These students were undertaking a project sponsored by the PCD directly concerning the durability of dust suppressants. Specifically, they looked at the water retention abilities and surface bulk loading of most dust suppressant options, in simulated climatic conditions equivalent to those of Thailand. These tests provided valuable comparative data about the dust suppressants' abilities to retain particulate matter from becoming suspended in the air.

The suspended particulate matter has a quantifiable relation to health care costs. By reducing the amount of dust by a certain percentage, an amount of savings to the government could be calculated from reductions in hospital visits; the government subsidizes such visits. This report presents a cost benefit analysis concerning the feasible dust suppression agents in a case study of Bangkok. By comparing the cost of application to the health care benefits, we show that some suppressants will save the government a considerable amount of money. This analysis is applicable to other cities, including Chiang Mai, Thailand's second largest city, where suspended particulate matter levels are reportedly four times higher than in Bangkok.

The benefits rise considerably upon taking into consideration the savings to the population in their hospital visit cost contributions, as well as the intangible gains to the general public that result from cleaner air. In addition, a reduction in maintenance to unpaved roads will result in lower costs for contractors and highway departments. Without including these supplementary benefits to justify any governmental expenditure, the government could save up to twenty-three million baht per year in health care subsidies by using polymers for dust suppression. However, the use of other suppressants can be similarly justified; the appropriate choice depends on factors such as availability, location, environmental impact, and climate.

Asphalt emulsions, polymers, and magnesium chloride from the project in Bamnet Narong should be excellent choices for controlling dust on unpaved roads in the near future to reduce levels of suspended particulate matter. According to the cost benefit analysis in this project, these agents can save the government a significant amount of money. The use of distillery waste should undergo further testing to ensure environmental safety; the use of this resource would release distillery factories of the burden of disposing of the material. Lignin from paper mills and soybean by-product should be further explored to see if these wastes are currently utilized or otherwise available for use on roads. Ultimately, decision-makers should consider the effects of dust on the citizens of Thailand; even if a suppression agent does not have monetary gains to the government, people's health will improve and the quality of life will surely increase for the population as a result of dust suppression. In Bangkok this improvement will benefit millions of people.

Chapter 1: Introduction

An economic boom that began in Thailand after 1985 greatly changed the city of Bangkok. Commercial buildings now dominate the palaces, government offices, and temples that Bangkok has been known for. A main reason for this growth was the large increase in investments by Japan in Asia. The $47 billion that Japan invested in Asia between 1986 and 1993 to manufacture goods for export, followed by similar actions from Taiwan, Hong Kong, Singapore, and South Korea, fueled a high rate of economic growth in Thailand as well as in other Asian economies (8).

The impact of this economic rise had a significant social influence in Thailand that caused an increase in population in the capital city of Bangkok. Bangkok saw its population rise from 6 to 12 million between 1981 and 1998, with an estimate of almost 20 million inhabitants by early in the 21st century (7,8). One resulting problem for Thailand has been developing its infrastructure to keep pace with the economy and population.

The rapid growth of industrialization has not occurred without problems, one of which is a devastating effect on the environment. Bangkok has a severe air pollution problem that is largely due to traffic congestion, which has become a way of life for Bangkok residents. Travel speeds in Bangkok are remarkably slow as a result of this congestion; they can fall to 2.5 km/hr, and as low as one km/hr in the center of the business district (7). To deal with the traffic problem, the Thai government has initiated a few major transportation projects. Such projects include the construction of an elevated highway and subway, both through the most congested areas of Bangkok. This construction continues and shows no signs of slowing, despite the economic decline of the late 1990's. A major cause of the increased air pollution levels is the increased construction activity, and specifically dust from the roadway construction. This construction has to work around existing traffic schemes, so unpaved roads are used throughout the process.

1.1 Dust Problems in Bangkok

Traffic deteriorates Bangkok's unpaved road surfaces, resulting in large amounts of dust becoming airborne. The airborne dust is called suspended particulate matter. The most dangerous part of this dust to humans and animals is the PM-10 particles; this classification refers to particulate matter smaller than 10 microns in diameter (14). As dust enters the respiratory and cardiovascular systems of humans, it contributes to many public health problems ranging from asthma to premature death, as well as to an unhappy population (17). Besides these health effects, particulate matter also creates visibility problems, damages materials, and deteriorates water quality. As an indication of the dust problem in Bangkok, the dust particle level rose to four hundred times the maximum level established by the Ministry of Science, Technology and Environment in February of 1996. The Ministry's maximum level, furthermore, is already over three times the declared maximum of the WHO (World Health Organization) (1).

1.2 Goal and Objectives

The goal of this project is to recommend dust control agents that would be suitable for Thailand, and specifically Bangkok, to use on its unpaved roadways. To determine the suitability of these agents, we will evaluate them for their dust suppression abilities, environmental impact, cost effectiveness, and availability or feasibility of production in Thailand. Once we have evaluated the potential agents for these factors, we will make recommendations to the appropriate governmental agencies.

1.3 The Importance of Undertaking this Project

Finding a suitable agent to control dust on roadway construction sites is an important factor in reducing air pollution. Although this project is based in Bangkok, Thailand, with recommendations made for Thailand, this project is of potential use to all places with unpaved road dust problems. It is not our results that will be applicable to other places, but the methodologies that we employ to generate our recommendations. Our methodologies take into consideration the local climatic conditions, environmental impact issues, and availability of suppressants. These factors will differ from place to place, but our methodologies allow for customizing recommendations for any location.

Factors for someone applying these agents to consider are environmental and climatic conditions, volume of traffic, and the type of traffic. Construction companies and governmental departments in Thailand will be able to utilize the results of this project for their specific project sites or unpaved roads. Construction companies and government departments outside of Thailand will benefit from the methodologies that we use in order to approach their dust suppression needs.

The results of this dust suppression project should be of particular interest to contractors of large-scale transportation projects in Bangkok. In February of 1997, the Office of Environmental Policy and Planning (OEPP) gave such contractors two months to reduce their dust and noise pollution (18). Compliance is very difficult in such a short period, but this action did demonstrate that the government is aware of the problem. The need for dust reductions in Bangkok is demonstrated by the city having three times the number of reported respiratory cases in comparison to the provinces, according to OEPP secretary general Saksit Tridech (18). The Bangkok Metropolitan Administration (BMA) has also said it will revise regulations to force contractors to follow pollution control limits, which include limits on amounts of dust being lifted into the air (18). Currently, the BMA has regulations to control dust on construction sites that include putting sheeting over buildings under construction, ensuring trucks have load covers, and having the wheels on the trucks cleaned (23).

The government of Bangkok is not the only party concerned with air pollution and dust from construction sites; the population is also fed up with the dust. The voice of the people was heard on June 6, 1997, when a flood of 500 calls complaining about pollution from construction sites overwhelmed a popular traffic station radio, Jor Sor 100 FM (24). The cause of the calls was due to Bangkok Governor Bhichit Rattakul leading an inspection tour of construction sites that day. These inspections were occurring with the help of Jor Sor 100 FM radio's helicopter, which was helping to locate sites that were in violation of city regulations on dust prevention. With this opportunity at hand, the people took advantage to directly voice their concerns to the governor (24). This concern is understandable, as in January of 1997, the Public Health Department reported that dust pollution had reached a critical stage in Bangkok (1).

1.4 Suitability of this Project as an IQP

The Interactive Qualifying Project (IQP) is a degree requirement that should examine "how science or technology interacts with societal structures and values" (22). The term *interactive* implies that an IQP might examine how society is affected by technology, or vice versa. The study of this interaction is at the heart of the IQP, and a common error that may arise is this project may turn out to be too technical or too social.

In comparing the requirements for the IQP with the project that is being laid out in this document, one is able to conclude that "Controlling Dust on Unpaved

Roads in Thailand" contains all of the elements that are necessary for an IQP. There is a technological side to the project, which involves the science of dust control, environmental and health considerations, and the engineering associated with construction projects. Also, there are social aspects that involve the costs to society of dust being in the air, and the potential benefits of reducing it. It may be that a proposed method suppresses dust well, but that it causes harm to the environment; we must consider this type of possibility so the recommendation is in fact beneficial. The project team will perform a societal impact analysis for each dust suppression agent that we are studying. Then, based on the outcome of this analysis, we will be able to make recommendations as to the best solution for improving Bangkok's and Thailand's dust problems.

The project entitled "Controlling Dust on Unpaved Roads in Thailand" clearly meets the requirements for an IQP. We will look at how the present technology is affecting society and then recommend an improved method that will have economic and other social benefits. The project's worth as an IQP only becomes more pronounced when one realizes that there is a great need for air pollution reduction in Bangkok. With this IQP we hope to contribute to the process of making Thailand, and especially Bangkok, a healthier place to live.

Chapter 2: Background and Literature Review

The problem of controlling dust from unpaved roads is not a recent development, as comparative studies have already been performed in a number of countries to determine suitable dust control agents. A logical solution to this problem would be to suppress the dust before it becomes airborne. Various agents can be used for such suppression; the present method of suppression in Thailand uses water to dampen dust particles. This method is not only expensive, but also ineffective for the climatic conditions of Thailand. Due to high temperatures, the water quickly evaporates, requiring frequent applications. Furthermore, the evaporation of the water loosens more of the road surface, exacerbating the problem. Research has shown that there are many other agents that may be better suited to the task than water.

The first part of this chapter will involve defining all of the relevant terms that will be used throughout this project. The relevant terms deal with defining what dust is as well as the terms that are involved in unpaved roads. Both sets of terms are necessary to understand the nature of dust and how it is generated from unpaved roads. Dust is merely a collective name for various kinds of suspended particulate matter, and the environmental problems arise from only a few members of this larger family. To get to the heart of the problem, a definition of the various kinds of dust will be necessary.

For this project, these various dust suppressant agents fall into four categories, namely salts, polymers, agricultural products, and petroleum products. Dr. Supawan Tantayanon, of Chulalongkorn University in Bangkok, Thailand, suggested these groupings; based on our research, we found that this was a good categorization of the potential agents. The salts consist of two main types, calcium and magnesium chloride. Polyvinyl Acrylic Emulsions are the only examined polymer. Agricultural by-products contribute many options, including lignin sulfonate, sugar beet extract, soybean oil by-product, and distillery waste. Also, there exists a field of petroleum products consisting of petroleum based resins.

The particulate matter in the air has obvious health effects that will be discussed in this literature review. Besides health effects, the project team will provide specific statistics that relate health effects to hospital visits, which are necessary for benefit analysis. Also to be discussed in this chapter are the potential environmental effects of dust and the environmental effects of the various dust suppression agents. Lastly, it is important to include data on climatic conditions in Thailand as well as the methodology research that is needed for the team to complete the project. This methodology research includes interviewing, cost benefit analysis, and environmental research.

2.1 Terminology

There is some technical terminology involved in this project. Dust is merely a collective name for different kinds of matter. Some of this matter is more harmful than others. Specifically, suspended particulate matter is more harmful because humans and other animals easily inhale it. To grasp exactly which particles are causing the problems in Thailand requires the differing kinds of matter to be defined. Furthermore, a basic understanding of unpaved road construction and its terminology is useful. These definitions are important so that it can be understood where dust is generated and how it gets into the air.

2.1.1 Defining the Various Kinds of Dust

A common mistake that people make when referring to dust assume is that there is only one kind. Dust is a name given to all kinds of particulate matter and it is important to differentiate between them. The difference from one type to the other is solely in size. The reason that the differentiation is based on size is that this parameter determines the effects that the dust has on animals, humans, and the environment. Larger particles can not be inhaled by animals, but they can cover vegetation. To give an overview of the different classifications of dust, Table 1 was adapted from an Australian study (37):

Table 1: Dust Definitions

Type	Definition of the type	Size range (μm)
Dust	Solid particulate matter (mineral, biological) capable of temporary suspension in the air, smaller than grit and larger than smoke	0.1-75.0 (up to 100)
Fugitive Dust	Dust arising from diffuse sources, not via a stack or duct designed to control their flow. The type of dust also disperses some distance from its source.	< 30
SPM (Suspended Particulate Matter)	The total mass of all of the particulate matter that is airborne.	< 100
Inhalable Dust	The fraction of air-borne dust that can enter the nose and mouth during breathing and can therefore be deposited in the upper respiratory tract.	<100
Respirable Dust	The fraction of airborne which, when inhaled, enters the gas exchange region of the lung, the alveoli.	< 9
PM 10	Particulate matter with an aerodynamic diameter less than 10 microns.	< 10

2.1.2 Unpaved Road Construction and Terminology

In this project we are concentrating on the dispersion of dust from unpaved roadways. The make up of an unpaved roadway involves some important terminology. This section will define words that are frequently referred to in this documentation, as well as describe how unpaved roads are constructed.

An unpaved road is constructed using two substances, called aggregates and fines. Aggregates vary in size from very large stones down to pebbles and are the larger of the two substances. The foundation of the road consists of the largest stones;

the rest of the road is made up of progressively smaller stones, with a top layer of pebbles. The distance from the foundation to the surface of the road is usually about 20 cm. This layering of different sized stones does not hold together very well; in this state, the road would disintegrate very quickly. The use of fines prevents this from happening. Fines are very small particles about the size of sand grains that are mixed in with the aggregates. This fills the spaces in between the aggregates, holding them together as though the fines were glue. The road will not readily disintegrate with this construction.

The effect of traffic on an unpaved road is that the tires pick up the fines from the surface and waft them into the air. The problems that result from this are two-fold. The first is that there is now particulate matter in the air that is known to cause many health effects. Secondly, the loss of these important fines from the road surface causes the road to degrade faster because of the loss of the aggregate glue. If the road becomes too degraded, then it is no longer usable for traffic.

2.2 Thailand's Climate and Seasons

The climatic conditions that exist in Thailand will have to be taken into account when determining how effective a suppression agent will work there. An agent that works in a cold and dry environment will not necessarily work in a tropical environment such as Thailand's. The climate in Thailand is hot and humid, and can be divided into three seasons. March through May is the hot summer season, June through October is the rainy season, and November through February is the cooler and dry season. In terms of climatic conditions, Thailand is divided into four regions, namely: Central, Northern, Northeastern and Southern region. Each of these regions has a slightly differing climate; but this difference is not a significant factor in determining which suppressant to use. As the goal of this project is to make recommendations that are suitable for all areas of Thailand, one climate and the three seasons must be taken into account.

The condition of a road will change depending on the weather conditions. Aggregate fines will stay on the road with a fair amount of rain. Too little rain means more dust in the air, and with too much rain the road becomes muddy and aggregates erode from the road. If a road receives a daily amount of rain it will not become too dry and dust suppression is not necessary. Dust suppressants lose some of their abilities at high temperatures, low humidity levels, or in a combination of the two. Dust suppression is also dependent on the amount of rainfall in the year, which changes from season to season. The amount and frequency of rain changes from month to month, and dust suppressants only work for a limited amount of time. It may be possible to utilize a different suppression agent in different seasons according to how dry or wet weather conditions have been.

Table 2 shows climatic data averaged over 1980 to 1989 in the central region of Thailand. The table demonstrates data corresponding to the three seasons previously mentioned. It also provides the temperature, rainfall, and humidity data that can used to analyze Thailand.

Table 2: Climatic Data for Central Region (38)

	Rainfall (Days)	Rainfall (mm)	Temperature (°C)	Relative Humidity (%)
January	0.8	1.9	26.3	61.0
February	1.2	17.6	28.5	67.2
March	1.6	21.5	29.9	66.2
April	5.6	46.1	30.9	68.2
May	11.1	48.9	29.9	74.5
June	13.8	37.3	29.1	77.1
July	13.9	52.4	28.7	77.7
August	18.4	44.0	28.6	79.1
September	17.3	51.7	28.2	82.3
October	13.9	85.5	27.8	80.7
November	5.0	36.8	27.1	70.4
December	0.4	0.5	25.1	60.4
Annual	103	444		

2.3 Health Effects of Dust on Humans

The fine particles that make up particulate matter are a great health concern to humans because they reach the deepest recesses of the lungs (17). These particles, as well as combinations of other air pollutants, are related to many significant health problems that include premature death, aggravated asthma, coughing, increased hospital visits, difficulty or painful breathing, chronic bronchitis, and decreased lung function. Furthermore, these health problems are significant because they contribute to absences from work and school (17).

Individuals who are at the most risk of suffering from exposure to fine particles are the elderly, people with prior heart or lung disease, children, and people with asthma. The elderly are at risk of dying prematurely from particulate matter; many of the thousands of hospital admissions due to exposure to fine particles are elderly people suffering from heart or lung disease. People who have pre-existing heart disease, chronic bronchitis, or emphysema are likely to require additional medical treatment from breathing the fine particles. Children are particularly vulnerable to respiratory problems since they breathe 50 percent more air per pound of body weight than adults do. In children, respiratory systems are still developing so there is a concern for the future health of lung function. Frequent childhood illness results in absences from school and limitations in activities. Lastly, people with asthma will have their condition aggravated by breathing fine particles. The aggravation will cause the need for more medication and an increased number of hospital visits (17).

These health problems are a serious issue in Thailand; Bangkok was ranked as the world's worst air polluted city by Japanese researchers in 1993. Those researchers also found more than ten types of carcinogenic-generating substances in the atmosphere. In five years, Bangkok moved from being the fifteenth most polluted city to the first. In 1990, a survey on pollution in Bangkok titled "Ranking Environmental Health Risks in Bangkok, Thailand" was conducted by the United States Agency for International Development (USAID), the United States Environmental Protection Agency (USEPA), and the Thailand Development Research Institute. The survey found that dust was a contributing factor in more than 1,400 deaths per year. Most of the information for the USAID survey was acquired by administering blood tests to Bangkokians. Table 3 reveals the substantial benefits of reducing the amount of particulate matter in the air.

Table 3: Bangkok - Morbidity and Mortality Associated with Suspended Particulate Matter. Estimated Impacts of 20% Reduction in Ambient Concentrations (36)

Health Impacts	Reduction in number of cases/year		
	Low	Mid	High
Restricted Activity days (RAD)	3,300,000	5,330,000	8,370,000
Emergency Room Visits (ERM)	3,120	34,600	66,100
Asthma Attacks (AA)	322,000	25,800,000	51,300,000
Chronic Bronchitis in Children (CCB)	863	78,600	156,000
Chronic Cough in Children (CCC)	537	90,700	181,000
Respiratory Hospital Admissions (RHA)	3,450	14,900	26,400
Respiratory Symptom Days (RSD)	159,000,000	200,000,000	251,000,000
Mortality Reductions			
Schwartz and Dockery (1991a) – SPM	152	405	658
Schwartz and Dockery (1991b) – SPM	459	761	1060

This table summarizes what would happen if the amount of particulate matter in the air was reduced by 20%. The table consists of three estimates; the low one denotes the most conservative prediction of reducing the particulate matter in the air, and the high one is the most aggressive estimate. For example, by reducing the particulate matter in the air by 20%, between 3,300,000 and 8,370,000 less people will have restricted activity days per year. For this IQP, the estimates that are going to be very important are the emergency room visits and the respiratory hospital admissions.

2.4 Dust Suppression Agents

The following sections provide information on the relevant aspects of dust suppression for each potential product. As some of the alternatives have only been used sparingly in isolated locations, and others not at all, there is not a great deal of data that is available for those agents regarding dust suppression on unpaved roads. In this section, an overview will be given of relevant information regarding the suppression agents. The materials that will be explored are calcium chloride, magnesium chloride, polyvinyl acrylic emulsions, petroleum based resins, lignin sulfonate, sugar beet extract, soy bean oil by-product, and distillery waste.

2.4.1 Salts

Two of the more widely used dust suppression agents are classified as salts. These agents, calcium and magnesium chloride, are examined in this section, along with their potential environmental impacts.

2.4.1.1 Calcium Chloride

Calcium chloride is a hygroscopic compound, meaning that it absorbs moisture from its surroundings, causing particulate matter, such as dust, to be weighed down (1,3,5). The calcium chloride dissolves in the moisture forming a clear solution that is extremely resistant to evaporation (2,5,11). The calcium chloride is further suited to dust control in that it lubricates the aggregate and improves the interlocking action (2,5). Calcium chloride is manufactured as a by-product of soda ash processing when ammonium chloride and lime react (4,11). This agent has been proven to work on different types of unpaved roads as well as in various types of climatic conditions (3). Its dust suppression ability was extremely diminished when the humidity dropped below 18% (6).

The product can be obtained in two forms, namely a 30 to 38 % solution with water or in a 77-80% solid flake form (4,10,11). Application of calcium chloride solution takes place by way of a tank truck with a rear mounted distribution bar (3,9). See Figures 1(a) and 1(b) for an illustration of possible application techniques. Using the 38% solution, experience has shown that the best dust control is achieved by using 0.35 to 0.55 gal/sq. yd. (2,3,4,10). Pre-wetting the surface prior to application will increase this salt's effectiveness (3). Application of the flake form of calcium chloride is done using a tailgate, spinner disk, or drill-type spreader on a pre-wetted road (2,4). With this form of the calcium chloride, the best results were obtained by using 0.5 to 2.0 lb./sq. yd., depending on the amount and type of traffic (2,10).

Figure 1(a) – Applying a Dust Suppressant
(http://www.lasvegas.com/realestate/REAug-09-Sun-1998/Front/7929616.html)
Tank truck with hose for manual spray.

Figure 1(b) – Applying a dust suppressant
(http://www.usroads.com/journals/rmej/9806/rm980604.htm)
Tank truck applying suppressant with rear distribution bar

2.4.1.2 Magnesium Chloride

Magnesium chloride works hygroscopically, similarly to calcium chloride, but some tests show that magnesium chloride holds on to more dust per mile than calcium chloride (11). Colorado State University has shown that total annual maintenance costs can be reduced with magnesium chloride by as much as 46% over untreated roads (11). Magnesium chloride is a by-product of salt-mining operations (28), and is corrosive to steel objects (31).

Magnesium chloride significantly loses its ability to resist evaporation at temperatures over 72° Fahrenheit (12) and begins to crystallize below 31 percent relative humidity (6), which means that it loses its ability to draw moisture from the air in hot and dry conditions. Extended periods of rainfall cause the magnesium chloride to leach into the ground, depleting the road of its dust control agent (28).

Magnesium chloride has been used extensively in the industrial setting with few reports involving environmental hazard. There have been no reports of malice effects from other products that contain magnesium chloride, such as fire extinguishers, casein glue, and floor-sweeping compounds. A literature search conducted by the United States Army Corps of Engineers shows that there was no evidence of long term hazards to people who come into contact with the substance or on the surrounding environment of the road. They also researched effects from the use of magnesium chloride on the deicing of roads with no findings of environmental detriment (28). However, magnesium chloride can increase pH levels in soil, thereby inhibiting root growth in plant life (28). The material is unlisted on the United States Environmental Protection Agency toxic wares list (32). Overall, it has been shown that magnesium chloride has little environmental risk (28, 32).

To apply magnesium chloride, Colorado researchers used a Mercedes Unimog and a hydroseeder. The surface should be pre-wetted in order to reduce surface tension in the road. If the surface is not pre-wetted effectively then the road may be too dry for the magnesium chloride to penetrate the entire surface, leaving a patchy dust controlled surface and greatly reducing the dust control abilities of the magnesium chloride. Once the magnesium chloride is applied it can take four hours or longer to cure. The degree of effectiveness is directly related to the cure time (28). In addition, some effort to compact the road enhances the degree of effectiveness. Compacting ensures a better bonding of magnesium chloride, water, and dust. If a road undertakes a heavy load of traffic then this may substitute for the compacting of the surface (28).

When a road is treated with magnesium chloride, and wetted methodically, the occurrence of crystallization is reduced. The re-wettings would be much less frequent than those required when using only water on unpaved roads. The water should be applied in amounts between 0.10 and 0.20 gallons per square yard (28).

2.4.1.3 Environmental Analysis of Salts

The use of calcium chloride as a dust suppressant has effects on the environment. A review of the literature revealed that very little research has been done to determine the environmental impact of using calcium chloride as a dust suppressant. However, a lot of research has been done regarding the environmental effects of calcium chloride when it has been used as a deicer. The results of the deicer studies are going to be comparable to the results of a dust suppression study in that the nature of the application is similar. A deicer is applied to an ice covered paved road, whereas the dust suppressant will be applied to an unpaved road, meaning that the effects on the environment should be comparable. When dealing with a dust suppressant though, the environmental effects are going to be less pronounced simply due to the nature of the runoff. Runoff is defined as those substances that are taken with the water as it leaves the road surface. In the application of deicers, a lot more calcium chloride is going to become runoff because the calcium chloride causes the ice to melt, and the resulting water, along with the salt, runs off of the road and into the surrounding area. For dust suppression, the salt works to absorb moisture into the road. In that way, the conclusion can be drawn that the effects of dust suppressants and deicers will be similar, but for dust suppressants they will not be as severe. The information that will be provided about the effects of calcium chloride on the environment is gathered from deicer studies.

The negative environmental effects of the calcium chloride come about by runoff. This runoff travels off the road and into surface water and groundwater. The water now contains a higher concentration of calcium and chloride ions that will effect the environment by various pathways. This water will surround the roots of trees and plants as well as function as the drinking water for animals, including humans. Fish, one of the more important food sources of Thailand, are very much dependent upon the consistency of the water that they live in. All of these uses for the water are going to be unbalanced by the fact that the water contains more salt than it had prior to the runoff. In order to gain an understanding of what is considered to be normal levels of chloride ions, Table 4 is provided.

Table 4: Chloride Content of Various Liquids (31)

Type of Water	Chloride Content (mg/l)
Rain Water	2
Upland Surface Water	12
Unpolluted River Water	Up to 15
Spring Water	25
Deep Well Water	50
Weak Sewage	70
Medium Sewage	100
Strong Sewage	Up to 500
Drinking Water	10-20 great variation though
Urine	4,500-5,000
Sea Water	20,000
Runoff from Calcium Chloride trial	3,645.69
Runoff from Magnesium Chloride trial	4,362.56

2.4.1.3.1 Impacts on Humans/Animals

The maximum level of chloride that has been set for human drinking water is 250 mg/l (31). This level was not set for reasons of health, but more for reasons of taste and palatability. In very dry climates, the drinking water naturally contains much higher levels of salt and no adverse effects have been reported. Little in depth study has been done on increased salt levels in humans, but even the highest levels encountered thus far have not shown to have adverse effects (31). In terms of other animals, livestock have been able to survive normally on levels of chloride up to 5,000 mg/l. The upper safe limit for poultry is 2,860 mg/l; for pigs it is 4,290 mg/l; for horses it is 6,435 mg/l; for cattle beef it is 10,000 mg/l; and for adult dry sheep it is 12,900 mg/l (31). Studies performed on rats and sheep have shown that excessively elevated levels (over 15,000 mg/l of salt) have interfered with the production of normal litters and normal lactation, and in some cases have been very toxic (31). Fish are some of the more sensitive animals when it comes to levels of salinity in the water. The main problem arises for fresh water fish, which are more sensitive to changes in salinity in water than salt-water fish. It has been shown that salt-water fish survive better in fresh water than vice versa. Threshold levels of chloride have been determined for various types of fish; levels exceeding these given numbers will be toxic to these fish. The threshold level of chloride for pickerel is 12,060 mg/l, and is 22,080 mg/l for white fish. Daphnia have a considerably lower tolerance for salt; they are immobilized by levels as low as 920 mg/l and killed at 1,830 mg/l. Salt-water fish have an easier time of changing salt levels, as they are constantly surrounded by salt in the water and have thus evolved to live with it.

2.4.1.3.2 Impacts on Plants

Plants absorb water by way of osmosis. Osmosis is the phenomenon by which water travels from an area of low solute concentration to an area of high solute concentration across a semi permeable membrane. This means plant cells have a relatively high solute concentration, and remove the water from the surrounding soil, which has a relatively low solute concentration. In that way, the plants take water into their system. As explained, runoff water also provides plants with their water, but in comparison to fresh water, runoff has a high level of solutes in it. Hence, the concentration gradient, so crucial to the process of osmosis, is distorted, and osmosis is slowed down or even reversed if the concentrations are high enough in the runoff. There is another problem with a change in the osmotic balance in that when this balance changes, absorption of other key elements for plant growth such as nitrates is hampered. The above problems all have to do with increased salt levels on the outside of the plant. However, if salt levels are increased on the inside of the plant, which will occur naturally with increased levels in surrounding water, other damage will arise such as leaf burn, leaf drop, twig dieback, and even death of the plant (31). The salt can enter the plant by two pathways, through the roots and through the foliage. Salt coated dust particles in the atmosphere settle on the leaves of trees. The salt particles resting on the leaves attract water from the air, resulting in a salt solution on the leaves, which is absorbed by the leaves and enters the plant (31). From this it is clear that the increase in salt levels in waters due to dust suppressants can have significant effects on plant life if the levels of chloride in the runoff are high enough.

2.4.1.3.3 Impacts from Salts

In order to determine if the use of calcium chloride as a dust suppressant is at all dangerous to plant and animal life, one needs to know how much chloride the runoff contains. From data obtained in Colorado dust trials, it was found that the average runoff from a single application was 3,645.69 mg/l per shower (31). This number is lower than most of the critical levels described above. Thus, the use of calcium chloride on an unpaved road is assumed to be reasonably safe. The only group that faces considerable risk with the use of the calcium chloride is fresh water fish, as their tolerance levels lie far below that of the average runoff from the calcium chloride.

In terms of the environmental aspects of the application of magnesium chloride, one quickly realizes that the effects would be similar to those of calcium chloride, which are described in Section 2.4.1.3. The environmental effects would be similar for both salts as they are brought about by way of the chloride anion, and not the magnesium and calcium cations. From the same road dust trials as before, it was found that the average runoff from magnesium was 4,362.56 mg/l (31). Thus the chloride runoff is quite a bit higher for the magnesium chloride than it was for the calcium chloride.

2.4.2 Emulsions

An emulsion is a mixture of a particular substance with water. Two emulsions are reviewed in this section, one with polymers and the other with petroleum. Polymers are long chain chemicals with soil binding properties. The polymer examined in this report is polyvinyl acrylic emulsion. The petroleum product examined is a petroleum based resin.

2.4.2.1 Polyvinyl Acrylic Emulsions

Polyvinyl acrylic polymer emulsion produces a film which covers dust on unpaved roads, thereby restricting its ability to become airborne. The polymer is supplied in concentrate form and requires dilution from 1:1 to 1:7 with water before application. The agent works well for all soil types and environmental conditions, although the effectiveness will vary as the conditions vary. Pre-wetting the soil improves how deep the polymer will penetrate the soil, but is not a requirement for effectiveness as with calcium chloride. Application rates range from 0.45 to 0.65 gal/sq. yd. and the road can be used immediately after the film is applied. In a test comparing the polymer with calcium chloride and soy bean oil by-product, it was found to be the least effective agent in terms of dust control (3).

2.4.2.1 Petroleum Based Resins

PennzSuppress D is a commercially available product that binds dust particles together using binding agents, dispersants, and moisturizing agents. It contains water-emulsified petroleum resins, without oil. The product should be applied to roads that are evenly leveled, free of potholes, crowned, hard, and compact, with the surface scarified to a depth of one to two inches. Extremely dry road surfaces should be pre-wetted and all open drains must be covered. It is applied under a pressure of twenty to thirty PSI (pounds per square inch) with a specially equipped spreader truck. The first application should be 0.25 gallons per square yard in two consecutive treatments. One treatment of the same volume must follow within seven to ten days. After application the road can be opened to traffic immediately. Frequency of reapplication depends on soil and traffic conditions (16). Recent tests conducted by the independent Midwest Research Institute confirm the effectiveness of the two step application process (11).

The suppressant is non-toxic to humans and animals, non-irritating to the eyes, non-carcinogenic, non-mutagenic, non-flammable, non-corrosive, classified as non-hazardous waste, non-inhibitive to plant growth, and shows low toxicity toward fish. These characteristics were determined by organizations such as Occupational Safety and Health Administration (OSHA), the Consumer Products Safety Commission (CPSC), the International Agency for Research on Cancer (IARC), the U.S. National Toxicology Program (NTP), the U.S. Department of Transportation (DOT), the National Fire Protection Association (NFPA), the Environmental Protection Agency (EPA), the Clean Air Act, and the Amended Clean Air Act. The largest problem with petroleum based resins is the equipment that is required to apply the agent. The high pressure and elevated temperature that are required for application of this suppressant make it very expensive to apply.

2.4.3 Agricultural and Industrial By-products

There are various wastes that result from the processing of agricultural resources and other industrial products. Some of these waste products have been used to suppress dust on unpaved roads. The agricultural substances that provide by-products that are reviewed in this report include lignin sulfonate, sugar beet, and soy bean oil. Also, the waste from the manufacturing process of alcohol is investigated.

2.4.3.1 Lignin Sulfonate

Lignin sulfonate is a by-product of paper mills, specifically from the lignin that binds fiber together to give plants and trees their firmness (12,13). This chemical works as a suppression agent by coating each dust particle and forcing the dust particles to stick to each other, forming a tightly packed surface. According to the Lignin Institute, the chemical is not harmful to plants, animals, or aquatic life, nor is it toxic or irritating to humans (11). The application of lignin sulfonate should penetrate one inch into the road surface. It is suggested that the chemical should be mixed with the top two inches of road material when being laid down on the road-in-progress. Pavement engineer Peter Bolander recommends applying 0.5 gallons per square yard on unpaved road surfaces (10). Application should occur once every two to three months; however, heavy rains can significantly reduce lignin's effectiveness, requiring additional treatment (31). The drawbacks to lignin sulfonate include water solubility, biodegradability, corrosiveness to aluminum, a slippery surface when wet, and an offensive odor (12).

The fact that lignin biodegrades is an important environmental characteristic of lignin sulfonate (31). The biodegradability means that lignin's presence in the environment is non-threatening when used as a dust suppressant. However, biodegradability is both a strength and a weakness. If the compound is biodegradable, then an application on the road will slowly degenerate by the weathering of nature. Lignin may need more reapplication than other dust suppressants because of its biodegradility. The improved packing of the road made by applying lignin sulfonate may offset the washing away of the lignin sulfonate. By reducing the runoff of the lignin, the time between repeated applications is longer, and in that way, more cost effective.

The way in which lignin works as a road stabilizer is that it coats all of the dust particles with an adhesive film and thereby binds the particles closer together. The lignin sulfonate also works as a dispersant which allows the dust particles to pack closer together forming a much stronger surface. An advantage of the particles packing closer together is that the amount of water that penetrates the road surface is greatly reduced since the water has less area to permeate. Less water in the road means that less mixing of water and lignin sulfonate will occur, reducing the amount of lignin sulfonate washed away into the water supply.

2.4.3.2 Sugar Beet Extract

A similarity to salt makes the concentrated liquid extract of beet molasses another material usable for dust control, although it has different advantages and disadvantages than a salt. The sugar beet molasses is a by-product of the sugar beet industry. Sugar beet molasses contains a high level of potassium chloride, making it hygroscopic like a salt, and giving it similar environmental effects as those discussed in Section 2.4.1.3. Runoff data is not available, making toxicity levels unknown. Neutral pH levels of the molasses results in less corrosion to passing vehicles and other objects made of steel. The president of the Indiana Association of Country Highway Supervisors cites that the use of sugar beet molasses works as well as calcium chloride at half the cost (9). Other experienced users of sugar beet extract dust suppressants note a pungent odor at high temperatures and humidities as a strong argument for not using it. After heavy rains a treated road will need additional treatment because the water soluble sugar beet molasses is mixed with an equal amount of water upon initial application.

2.4.3.3 Soy Bean Oil By-product

Soapstock is an acidulated soybean oil by-product created from the refining process of soybean oil. It is an environmentally friendly, biodegradable material that does not migrate into the ground water or harm agricultural crops. When this agent is applied to roads, it penetrates the surface and bonds the bed material forming a protective shield with no dissolution or toxic run-off. The application rate for first time usage is around 0.25 gal./sq.yd. and costs can range from \$1.12 to \$1.50 per gallon in the United States. For heavy traffic, the rate may need to be increased. Although the oil is more expensive than calcium chloride (in the US), soapstock will last an entire summer, whereas calcium chloride needs to be applied more often (15).

Soapstock is a liquid oil at temperatures above 35° Fahrenheit and should be applied at temperatures above that threshold. The warmer the oil is, the faster it penetrates the surface. The oil does not emulsify with water and should not be pre-mixed with water as some other dust suppressants are. It is recommended that the road surface be dry prior to application, with a grading of 1" to 2" of loose material on the road surface. Once the product is applied, watering or rain may help it penetrate the surface. It normally takes the oil 4-6 hours to penetrate to its depth of 1". It is also noted that a reduced rate of application can be used on the same surface at the second time of application, without a loss in effectiveness (15).

2.4.3.4 Distillery Waste

Current literature lacks sufficient data concerning the use of distillery waste on roads. Dr. Supawan Tantayanon suggested the use of distillery waste, specifically, the waste from beer or whiskey production, for dust suppression. The waste product is currently being used in a dust suppression experiment in the soil mechanics laboratory at Chulalongkorn University in Bangkok, Thailand.

2.5 Methodology Research

Many different methods can be undertaken to find the best dust suppressant to use on unpaved roads in Thailand. In order to perform these practices the project team must first understand how to use such methods. Literature reviews, journal searches, handbooks, and case studies were reviewed to find the most appropriate methods and learn how to use each method.

2.5.1 Interviews

The project team conducted interviews in Thailand, so it was important to be knowledgeable about how to design, execute, and analyze an interview. This information was found in a packet titled "Introduction to Interviewing Techniques" By James K. Doyle (29).

There are aspects of an interview that should to be taken care of before the actual interview. It is important that the interviewees know why they are being interviewed and why their participation is worth their time and effort. It is just as important that the interviewers have a solid understanding of the information they are interviewing about. Interviewers must also be aware of certain ethical considerations. These considerations include obtaining the "informed consent" of the subjects, which lets them know their rights and the interviewers' limitations. In addition, confidentiality is to be ensured unless a waiver is signed. This assures the interviewee that promises will be kept, such as allowing summaries of interviews to be reviewed for accuracy. Lastly, the interviewer should write a thank you letter out of courtesy (29).

The interview method that will be implemented in Thailand is the in-depth qualitative interview. This particular technique for interviewing is unstructured and flexible, as the questions are mostly open ended with the intent of gaining detailed information about the interviewee's personal perspective and experiences. As these interviews are generally time-consuming to carry out and analyze, only a limited amount of people can participate. Due to this limitation, it is important that the people interviewed will be the most informative. In terms of this project, for example, project managers would be the most appropriate interviewees from the roadway construction industry. The only drawback to the restriction of the number of interviews is making sure that the participants are a good representative of the larger group about which inferences will be made. There also exists another hindrance that is specific to this project: an interpreter is likely to be needed to translate the Thai language into English. In qualitative interviewing, the proper number of interviews has been done when there is complete understanding of the topic and the information from participants becomes repetitive (29).

In preparing for qualitative interviews there is no need to plan them out in specific detail. The key to preparation is to know the important topics that need to be covered, how to phrase the questions about these topics, and what degree of detail should be achieved in the answers. This does not, however, mean the interview need not be well organized (29).

Qualitative interviews are usually divided into three stages. The first stage is to find out the background of the interviewees, which should include the relevant experiences they have had and how they came to their current status. The second stage deals directly with their present experiences that pertain to the interviewer's topic. The final stage is for the participants to inform the interviewer about the meaning their experience has for them. Following these stages guarantees that the interviewee's opinions and judgements are given after careful reflection (29).

The actual process of giving a qualitative interview can be very difficult for the researcher. The difficulty arises from many demands being placed on the interviewer at one time. These demands include asking questions, paying attention to the interviewee, taking notes, following the agenda, keeping track of time, noticing nonverbal cues, and deciding on when to try for more information or to move on to the next question. Important tips on interviewing techniques include not dominating the interview with talk but focusing on listening, asking open ended questions, giving clues for determining the amount of detail an answer should have, and asking questions in a logical order. Other important factors are to follow up questions when clarification or more details are needed, avoid leading questions, do not interrupt the interviewee unless he or she has strayed completely off track, and to have a balance between a formal and casual style, which allows the participant to be comfortable. Lastly, it is important to end the interview on a positive note and to have the option of future contact for further questioning or clarification of something from the interview (29).

The objective of a qualitative interview is to develop interpretations and explanations from the interview data. Therefore, it is extremely important for the data to be recorded word-for-word, which allows the information to be thoroughly reviewed and analyzed without misinterpretation. A tape recorder is the best method for collecting interview data because it is difficult to take notes while conducting the interview. Also, taking notes requires the interviewer to decide on what is significant to write down and leads to editing the interviewee's comments, which can later be misinterpreted. The editing of responses can also make it difficult for other people to follow what was said. As this project is done in a team of three, it could be effective to have one person conduct the interview while the other two members take notes, especially if tape recording is not possible (29).

Qualitative interviews lead to a vast amount of collected data. The first part of analyzing this data is to reduce it into a manageable level. The reduction is done by determining which portions of the responses are most useful, important, and interesting. Then this abbreviated version of the data can be analyzed into a final report. In order for readers to believe that the analysis in the final report is justifiable, it must be established that the analysis was based on careful review of interview texts, that inconsistent data between subjects was examined, and that the process of analyzing was thoroughly explained (29).

2.5.2 Cost Benefit Analysis

Cost benefit analysis is a study in which one tries to evaluate whether or not an investment is worth making. A traditional cost benefit analysis entails weighing the cost and benefits of a proposed action to doing nothing. A lot of factors come into play when making such a decision, and many of them are not quantitative because they involve placing a price upon such things as human pain or suffering. However, the idea behind a cost benefit analysis is to determine whether or not an investment will generate more benefit than using the resources elsewhere (33).

2.5.3 Environmental Impact Analysis

Environmental impact analysis considers any possible change in the environment caused by an activity or project. The environment can be defined as a combination of natural and physical surroundings and the relationship of that environment with people (26). Traditionally, environmental impact constitutes any change on a societal level, which may include shifts in societal values or norms, economic change, chemical transformations, energy source variations, noise quality improvements or detriments, or the effects on plant or animal life (25, 27). In order to perform an environmental assessment there must be a complete understanding of the proposed action and the affected environment, and the possible impacts of implementing the project must be determined. The final part of the analysis is to report the results of the assessment so the impacts can be used in the decision-making process (26).

For this project on dust suppression in Thailand, the environmental study will be less inclusive than the many aspects that the definition of environmental analysis entails. The economic aspects, population considerations, and societal influence are covered at other points in the report. The environments directly surrounding the road are the key areas of focus, and it should be determined what the boundaries of this area will be. In Thailand, the effects of runoff into the Gulf of Thailand are also an important factor. The analysis in these areas should include effects of runoff on surface water, the water table underground, vegetation, animal and aquatic life, and other factors that will be noted upon observation of various roadway sites. Another important factor to consider is how drinking water is supplied. According to Dr. Supawan Tantayanon, drinking water in Bangkok comes from the rivers, and then is treated to meet safety standards.

There have been many methodologies developed in order to perform an environmental assessment. Choosing one of these methodologies is dependent upon the type of project being performed. Also, there are some key considerations that should be looked at before making this determination. These factors include application, alternatives, public involvement, resources, time, familiarity, issue significance, controversy, and administrative constraints. *Application* means deciding if the environmental analysis is to be used for a decision, a regulatory compliance, or an information document. In terms of this project, a decision document analysis is appropriate, as the best course of action is trying to be determined, namely, which suppressant to use. *Alternatives* refer to looking at the degree of impact that exists between the choices. The *public involvement* factor does not apply to this project; the public is already aware of the dust problem and the health effects from it. The *resources* for conducting this project are mainly limited to university facilities. The project team consists of three college students working with an advisor and a liaison. The team has two months' time to complete the project, money is limited, and there is only permanent access to one computer. In terms of *familiarity*, the team has limited knowledge of the issues and methods associated with the project. The *significance* of the project's issue is enormous as far as controlling dust on unpaved roads in Thailand; there is an extensive air pollution problem in Bangkok, to which dust is a key contributor. There is no *controversy* over the use of dust suppression agents on unpaved roads in relation to the agents that are currently being used in other countries. Lastly, *administrative constraints* are also non-existent as the project is being completed by students through university advisement.

Once those factors have been considered, the methodologies can be examined in terms of how impacts are identified. There are six types of categories for methodologies. These categories include ad hoc methods, overlays, checklists, matrices, networks, and combination computer-aided methods. The *ad hoc* methodology provides broad areas for assessing impacts. Examples of this methodology include impacts on lakes, vegetation, forests, etc. An *overlay* methodology is based on maps of a project area's environmental characteristics. These characteristics include physical, ecological, social, and aesthetic; the impacts are found by comparisons of these characteristics within the specified area. The *checklist* methodology provides a list of environmental parameters by which impacts are evaluated; this can be valuable when repetitive actions are performed under similar circumstances. *Matrices* incorporate a list of project activities and a checklist. This methodology allows cause-and-effect relationships between specific activities and impacts to be recognized. A *network* methodology uses a list of project activities to establish cause-condition-effect relationships; the network is utilized to identify that a series of impacts may be caused by a project action. *Combination computer-aided* methodologies use matrices, networks, models, and a computer aided systematic method to analyze multiple aspects of the environmental impact of undertaking a project; this methodology is far too advanced for the scope of this dust suppression project.

One method that the United States Corps of Engineers utilized to evaluate the environmental effects of dust suppressing salts is by observing similar deicing salts on paved roads. Specifically, part of the team monitored the levels of toxic materials found in storm drains on the roads. Once samples were collected, the content was analyzed for potentially toxic materials. The collected samples were put through a variety of tests at independent laboratories to find the hazards involved with using the deicing salts. The researchers also monitored local wells to find any leaching effects due to chemicals put on sample lengths of dirt roads. The storm drain tests coupled with the well tests gave the final result of whether or not the dust control salts could potentially harm local life.

Chapter 3: Methodology

In this chapter, we provide a detailed description of how we conducted this project, and why we chose to do it in that way. We needed to collect and analyze a large amount of data in order to achieve the project goals. To do so in the allotted seven weeks, we had to develop clear methodologies to ensure that all aspects of the project were thoroughly examined. Furthermore, our task was more demanding because we were carrying out the project in a foreign country, where an unfamiliar language and culture posed many barriers, resulting in the simplest of tasks taking longer than anticipated.

Our goals for this project state that we would evaluate various dust suppression agents for their cost effectiveness, environmental impact and availability in Thailand. To meet the goals, we developed methodologies to address each of these factors. We designed an approach to deal with the cost effectiveness of the agents based on a cost-benefit analysis. We approached the environmental aspect by conducting an environmental impact analysis. Lastly, we decided to tackle the issue of availability in Thailand by interviewing people knowledgeable in the field. Having performed all the methodologies, we had to interpret all of the data and make recommendations. We did this using a recommendation methodology, which we also described in this chapter.

3.1 Project Preparation

Information gathered at Worcester Polytechnic Institute (WPI) and from other sources provided us with an understanding of the dust problem and helped us identify project elements that we could only accomplish in Thailand. The primary language of English, along with other conveniences found in one's homeland, eased the pursuit of resources invaluable to this project. Our research at WPI was aimed at finding out what literature existed about the dust problem and current road dust suppression, as well as learning about environmental studies, cost benefit analysis, and interviewing techniques. In this section we described in detail how these methodologies, carried out in the United States, were developed.

3.1.1 Background Literature Search

Literature searches completed in library databases revealed relevant books and journal articles about unpaved road dust suppression. The World Wide Web also provided an excellent way to find contact information on businesses and researchers working with dust suppressant agents. The follow up of references from these initial sources greatly increased the wealth of background knowledge. Many sources provided lists of company contacts. Phone, fax, letter, and e-mail communications established contact with many of these companies and researchers. The contacts supplied professional reports, cost effectiveness information, manufacturers' pamphlets, material safety data sheets, and other information about products used for dust suppression and/or their environmental effects.

3.1.2 Environmental Analysis Research

We divided the process of finding an appropriate method to perform an environmental impact analysis into two sections. Various uncovered methods provided a basis for us to decide on the single, best procedure for the problem. Then, in order for us to evaluate the various agents for their environmental impact, we mainly used information collected by other researchers on this issue.

3.1.2.1 Researching Methods of Environmental Analysis

After gathering background information about dust suppression agents, we evaluated the agents in terms of their environmental impact. Extensive research in library databases familiarized us with the existing methodologies of analysis developed by experts in the field. The most effective source of impact analysis came from previous case studies because they exemplified the implementation of completed processes. The case studies functioned as a framework for the analysis that we performed in Thailand.

3.1.2.2 Determining Appropriate Environmental Analysis

Once we obtained several environmental analyses and case studies to take under consideration, we were able to adjust their scope to suit our project. All of the found methodologies had one thing in common; they were at much too large a scale for the goals of this project. That is, the implemented projects were far more intrusive to the environment than applying a dust suppression agent to an unpaved road. When a project becomes more intrusive, many additional factors come into account such as the removal of trees, increased traffic, altered aesthetics, increased pollution, and many other environmental effects. A large-scale project would also take into account issues such as nutrient balances in the surrounding soil and the effects on the proximate water table. A dust suppression project would only have to look at the latter list because of the nature of the project. When applying a dust suppressant the environmental risk arises when the agents run off or wash out of the road and into the surrounding area. The risk is in how these agents will interact with the environment and it is those effects that we took into consideration. Thus, the scope of a dust suppression project differs from that of the larger projects for which most environmental impact analyses are designed.

Accordingly, we chose a project of similar scope for our model. We then identified and added new factors relevant to the issue of dust suppression and dropped issues of incorrect scale and irrelevance. This provided an environmental assessment approach that was appropriate for the conditions in Thailand. The final analysis will incorporate the results of this environmental study.

3.1.3 Cost Benefit Analysis

The first aim of a cost benefit analysis is to demonstrate that there is a need for action. For this project, it can be argued that a need has been demonstrated to control dust on unpaved roads. First, the Thai construction companies already use water to control their fugitive particles; second, the government has set regulations for allowable SPM and PM-10 concentrations in the air of Thailand. Nonetheless, due to the severity of health problems associated with particulate matter, further analysis is warranted to evaluate the merits of taking such actions.

A fundamental difference exists between the cost benefit analysis we performed in this project and a traditional cost benefit analysis. The latter compares the costs and benefits of a solution against the costs and benefits of doing nothing at all. For our project, we analyzed the costs and benefits of using potential dust suppression agents to determine if they are justified compared to the current means of dust suppression, that of using water. We were able to do this because the dust levels in Thailand's cities, where the problem is the most serious, results from the application of water to unpaved roads. If no water were applied to these roads the air quality problem would be worse.

Our cost benefit analysis consists of comparing the monetary costs to the Thai government of using dust suppressants to the monetary benefits the government will reap by using the same agents. Due to the high levels of particulate matter in the air, many people have to visit the hospital. As the government subsidizes such visits, they would save money if the number of visits were reduced. Lowering the levels of particulate matter in the air can reduce the number of people going to a hospital. Hence, by applying an effective dust suppressant to unpaved roads, the SPM level can be lowered, resulting in a smaller percentage of the population going to the hospital.

The people that no longer go to a hospital represent savings in governmental health care expenditure. This saving can be compared to the total cost of applying the different agents necessary to bring about the above SPM reduction. This comparison will demonstrate if the application of an agent results in an overall savings or expenditure.

Once we decided how we were going to quantify the costs and the benefits, we had to obtain the necessary data for conducting the analysis. This data included the percentage of people who visit the hospital due to SPM, how much the government contributes toward such visits, the reduction in hospital visits caused from a given reduction in SPM, and the costs associated with applying the various suppression agents in Thailand. In determining how to collect these pieces of data, we had to discover what resources were available on site. The strategy behind this involved searching the World Wide Web for places in Bangkok that were going to have population and health statistics. This method produced some data, but at this point research ended until we were in Thailand and had a better idea of what was feasible and who to approach.

3.1.4 Interviewing

Before we could conduct interviews, we had to learn how to plan, implement, and analyze them. Specifically, we predetermined the questioning technique, questions, and goals of the interviews. It was important to be knowledgeable about all aspects of the interviewing process since interviews were a major factor in the collection of data and information for our analysis.

3.2 Project Execution

Upon arrival in Thailand, we had to refine and carry out our methodologies in order to achieve the project goals. These methodologies included a data search, site assessment, interviews, environmental analysis, cost benefit analysis, data collection, and a recommendation methodology. Included in the interviewing methodology was a contact finding meeting/interview, question development, and interviews with a regulation expert, a contractor, potential producers or suppliers, and a person knowledgeable about public health. We divided the cost benefit analysis into two main parts, the cost determination and the benefit determination. The next methodology, data collection, informs of the experiments that were conducted by two graduate students at Chulalongkorn University. Lastly, the project team used a recommendation methodology that incorporates the results of the other methodologies to achieve our goal.

3.2.1 Data Search

The first action we undertook in Thailand was to collect data on production, maintenance, and water application costs related to unpaved roads. Furthermore, we gathered data on how dust affects the number of hospital visits of Bangkokians and their losses in daily wages. We also looked for information on how the population would be affected by a reduction in the amount of dust in the air. This data delineated the benefits of using a dust suppression agent instead of water.

In order to locate the data that we were looking for, we needed to get an idea of where to obtain this data. For determining road maintenance and water suppression costs, we decided to interview contractors. To obtain data on the population, places such as the World Health Organization in Bangkok, the Department of Public Health at Chulalongkorn University, and the Pollution Control Department were approached. Also, the Thailand Information Center, located in the central library at Chulalongkorn University, was found to be an excellent source for obtaining health statistics related to particulate matter specific to Thailand.

3.2.2 Site Assessment

Our site assessment in Thailand included investigating unpaved roads in Bangkok, Chiang Mai, and various other areas in Thailand. Investigating these roads allowed us to gain a better idea of roadway conditions and the scope of the problem. Primarily, we looked for the levels of pollution due to dispersing particles, and observed soil types in consideration of necessary application rates. At the sites, we identified important considerations for applying a suppression agent, such as agriculture, vegetation, water sources, animals, housing, and any other relevant conditions in the area immediately surrounding the road.

3.2.3 Interviews

This project involved collecting a great deal of information that was not available in books or other sources, such as information on unpaved road maintenance, dust suppression, and regulatory policies. Accordingly, we decided to interview people who would be able to provide us with it.

We first identified the groups of people that we wanted to interview. Given the nature of the project and the goals, we planned to perform four types of interviews. Next, we had to find people that fell into these categories, and then we set up interviews with these people. As this would have been a difficult task for us to perform in a foreign environment, we were aided by Dr. Supawan Tantayanon and Mr. Mike Gerson, WPI alumni familiar with the goals and subject matter of the project.

3.2.3.1 Contact Finding Interview/Meeting

The first interview that we conducted was a contact finding interview. On January 21, 1999 we talked to Dr. Sangsant Panich and Dr. Wong Pun. Dr. Sangsant Panich works for a variety of companies that deal with air and water pollution. He was working in conjunction with the Thai Pollution Control Department (PCD) on ways to reduce the amount of SPM in Thailand's air. As the dust from unpaved roads is a contributor to SPM, Dr. Sangsant Panich had been looking into ways to remedy this. Dr. Wongpun Limpaseni was also working with the PCD on this project, but his focus was more on the effects of particulate matter in the air than it was on ways to reduce it. Given their backgrounds in the field, these two gentlemen knew a lot about dust and its suppression in Thailand, and would be able to help us in finding the information that we needed.

The goals of this discussion were to become acquainted with the field of dust suppression and the people active in it. We were specifically trying to find people who knew about air pollution regulations and the effects of particulate matter upon populations. We were furthermore seeking to interview people who knew about dust suppression agents, people who were interested in supplying or producing the various agents for use in Thailand, and construction site managers who would know about unpaved roads. All of these people were essential to this project, but as we came from a different country, it was difficult for us to know whom we could interview from these four groups. For that reason, it was important that we talk to someone who is knowledgeable in the field first. This contact finding interview also placed us in touch with other contacts that the experts deemed important, but we had not thought about approaching.

3.2.3.2 Question Development

The remaining four types of interviews developed from the information that we received during the contact finding interview. They include the potential producer interviews, the agent expert interviews, the policy maker interviews, and the construction site interviews. All four of these interviews were mainly set up in the format of a standardized interview. When talking with these people it was necessary for us to gain specific information from their respective areas of expertise. It was also important for us to allow the interviewees the opportunity to enlighten us about any other relevant aspects of their expertise that we could apply to our project. We accomplished this by ending each interview with an open-ended question.

3.2.3.3 Regulation Expert Interviews

The first interview that we set up was with a policy maker. On January 25 1999, we interviewed Dr. Noppaporn Panich, a chemical engineer working at the Environmental Research Institute at Chulalongkorn University in Bangkok, Thailand. Her research focuses mainly on air pollution and the control thereof. Aside from her research, she was particularly beneficial to interview as she had worked in Australia during the previous year on controlling fugitive dust from coal mines. Many of the dust control techniques used in mines are similar to those used for unpaved roads, giving her first hand experience with the dust problem and its suppression. However, the main reason that we interviewed her was that she had recently worked with the Thai Pollution Control Department on a large research project concerning particulate matter in the air in Bangkok. Based on the outcomes of this research, she drafted regulations for the Bangkok Metropolitan Administration that aimed to reduce the amount of particulate matter in the air. These regulations were submitted to the necessary government agencies for implementation. Based on this work, she was knowledgeable on the current air quality regulations for Thailand as well as on working with the government for implementation of regulations. These areas of knowledge were very applicable to this project, making Dr. Noppaporn Panich a great resource.

The aim of this interview was to find out what the current regulations were on dust suppression and air quality in Thailand. Furthermore, we hoped to gain insight into how the Thai government works regarding the issues of regulations and their implementation. These issues were important for us to become aware of the current regulations. Knowing the regulations enabled us to determine if there would be any merit in recommending new, more stringent regulations.

The effectiveness of a given dust suppressing agent is determined by how much particulate matter it prevents from becoming airborne. In order to determine the most cost-effective agent for Thailand, it was necessary for us to know the target levels of particulate matter. Knowing these levels allowed us to recommend an agent that would provide Thailand with the best opportunity to reach their targets. Also, it was key to know how regulations become implemented in Thailand, so that we could direct the final recommendations to the appropriate people. Given Dr. Noppaporn's background, recent work, and aims of this interview, we drafted questions for her that can be viewed in Appendix A.

3.2.3.4 Potential Producer/Supplier Interviews

Two of the factors we evaluated the different dust suppression agents for are their cost and availability in Thailand. In essence these two are interrelated, since if an agent is available in Thailand, it is likely to be cheaper than if it has to be imported. To find out exactly how available the dust suppression agents were, we interviewed a series of potential producers and suppliers. Producers are either already producing, or looking into producing, the agents that we are interested in. The suppliers already supply or are thinking of supplying, the agents to Thailand. In both cases we interviewed these people to find out what costs would be involved in acquiring the agent and what the volume of supply would be. We tried to explore the availability of as many of the agents as possible and as a result we interviewed a polymer supplier, a producer of sugar cane molasses,and a supplier and producer of salts. In this section we explain who we talked to and why.

3.2.3.4.1 Polymer Supplier Interview

On January 26, 1999, we interviewed Mr. Ekarin Pongkajiratipa of Rohm and Haas Chemical (Thailand) Ltd. The aim of this interview was to determine what the possibilities were of supplying a suitable polymer for use on unpaved roads in Thailand. We also sought to find out what the costs were of supplying and applying their particular type of polymers. Furthermore, we aimed to gain more insight into the use of polymers as dust suppressants as well as to learn of any side effects that might be associated with their use. It was important to know whether or not this dust suppressant was currently available in Thailand, as that would greatly affect the polymer's cost. Documentation of polymers used for dust suppression was limited; due to this, it was important that we gain as much information as possible about the polymers so that a complete analysis could be performed. Based on the expertise of Mr. Ekarin Pongkajiratipa as well the aims of this interview, questions were drawn up and can be viewed in Appendix A.

3.2.3.4.2 Producer of Sugar Cane Molasses

On February 2, 1999 we talked to Mr. Theera Sanguandeekul of Khon Kaen M.D.F. Board CO., LTD about the potential of using sugar cane or sugar beet molasses as a dust suppressant. His company produces sugar and many other products made from sugar cane. We talked to him about the availability and cost of molasses as well as the feasibility of using this agent in Thailand. Furthermore, as information about sugar based dust suppressants was limited, we hoped to gather some information about their use and previous experiences others may have had.

3.2.3.4.3 Potential Supplier/Producer of Salts

The first interview that we had concerning salts in Thailand was on February 2, 1999, when we talked to Mr. Kajorndej Sawangaroon, marketing manager for Chemical Enterprise CO., LTD. This company imports both calcium and magnesium chloride to Thailand. We asked him about what the costs involved in this importation were, as well as what the potential to produce the salts here in Thailand may be. We also inquired into his experience with salts as dust suppressants and asked if he was aware of any environmental affects involved in their usage. Lastly, we wanted to find out if he knew of performance differences between calcium and magnesium chloride.

The second interview concerning salt supply in Thailand was with Dr. Anant Suwanapal, the director of the Department of Mineral Resources, on February 24, 1999. The government is implementing a large-scale project in central Thailand for the extraction of potash used in fertilizer. A by-product of this extraction process is a magnesium chloride solution. We asked Dr. Anant Suwanapal about the possibility of using this magnesium chloride for dust suppression purposes. We inquired about the projected supply of the magnesium chloride and about the costs involved in obtaining the solution. We questioned him further on what government regulations we would encounter in using it, and whether or not he was aware of any environmental effects from the use of magnesium chloride on roads.

3.2.3.5 Construction Contractor Interviews

The third type of interview that we performed was with a construction company, since many of the unpaved roads in Bangkok exist on construction sites. On February 3, 1999 we interviewed Mr. Komol Pinyosukhee who was deputy managing director of The Civil Engineering CO., LTD. His company has many construction projects throughout Thailand, and specializes in road maintenance and construction. The main goal of interviewing him was to find out what costs were involved in maintaining unpaved roads and controlling the dust on them with water. Obtaining this information was important to us, as these costs were a part of our economic analysis. Also, we would be able to get a sense of the contractor's willingness to use chemical dust suppressants, as well as any other input he would have on the subject of dust suppression. With these goals in mind, as well as the knowledge of which questions a construction manager could answer, we developed questions for the contractor that can be seen in Appendix A.

3.2.3.6 Experts

There were many experts in a variety of fields that were able to help us in reaching the goals of our project. We identified some key people that would be able to help us in areas of our projects that we would otherwise have very little grasp on. As such we talked to a civil engineer, a wastewater expert, and an expert in public health. In this section we discuss exactly who we talked to and why they may be important to us.

3.2.3.6.1 Civil Engineer

On February 10, 1999 we talked to Dr. Supot Teachavorasinskun. He was conducting experiments with various dust suppression agents at the Soil Mechanics Laboratory at Chulalongkorn University. As such, he knew a lot about the effectiveness of many of the agents that we were looking into for use in Thailand. We asked him about his experiments and unpaved roadways in general as well as any information he may have on availability and environmental issues.

3.2.3.6.2 Water and Environment Consultant

On February 10, 1999 we talked to Dr. Suchint Phanapavudhikul about his experiences with distillery waste as well as his knowledge about the environment. He is the managing director for a company called Water & Environment Consultant

Corp., Ltd. Dr. Suchint Phanapavudhikul's experience with distillery waste comes from the fact that his company advises twelve distilleries in Thailand about the disposal of their waste. We asked him about availability, cost and environmental impact of using distillery waste to suppress dust and whether or not it was even effective. This was one of the agents that we knew the least about, so we asked him very specific questions about what distillery waste is and how it works as a dust suppressant.

3.2.3.6.3 Public Health

On February 16, 1999 we talked to Dr. Nuntavarn Vichit-Vadakan, Assistant Dean for Research and Information in the College of Public Health at Chulalongkorn University. Given her position at the university and the work that she had done on the effects of particulate matter on the population, we interviewed her to further complement our economic analysis.

3.2.4 Environmental Analysis

After a careful review of the scope of this project, we decided upon a feasible form of analysis to examine the environmental aspect of the project. To determine which dust suppressant was suitable for Thailand, we sought to identify the environmental impacts of applying each suppressant to make sure any dust suppression was worth the environmental harm caused. The impacts also needed to be known in order to make comparisons between the agents.

Environmental factors that were considered in this analysis were those to be caused from the leaching and/or runoff of the product after it had been applied to an unpaved road. The exact environmental impacts to be evaluated for a given site depend on the location of the road in respect to such things as housing, vegetation, and water supplies. However, we needed to make general recommendations, so we divided the potential areas of impacts into three categories: plants, animals, and water. The different aspects of water that were considered were groundwater, which includes the water table under Thailand, and surface water, which mainly includes the Gulf of Thailand and Thailand's four major rivers: the Chao Phraya, Mae Klong, Tha Chin, and Bang Pakong. The rivers were of particular importance as they provide water that is treated and used for drinking. It was also important to remember that the three categories of plants, animals, and water were all interrelated in some way. Impacts on the water cause impacts on both plants and animals, as they use this water for survival. The Gulf was important due to much of Thailand being only one to two meters above the water table. This meant there was a strong possibility that substances mixed in with the groundwater would end up in the Gulf. Suppressants that end up in the Gulf of Thailand may have great effects on the wildlife there. This is potentially a great problem because a lot of people rely on the fish from the Gulf. For that reason, we had to evaluate the effects of the various agents upon the fish in the Gulf.

With those factors in mind, we could evaluate dust control agents to see how significantly the agents would affect each factor. Once this analysis was conducted for each possible agent, the environmental analysis would be available for determining the final recommendations.

3.2.5 Cost Benefit Analysis

A cost benefit analysis consists of measuring costs and benefits on the same scale and then comparing them to each other. The main goal in performing our cost benefit analysis was to show the economic benefits, to the government, of using dust suppressants in Bangkok. We believe the government has the potential to save money from applying suppressants to unpaved roads.

Air pollution forces many people to visit the hospital every day. These visits not only cost the individual, but also the government, as they subsidize the health care system. If the amount of dust in the air is reduced, fewer people will visit the hospital, which will represent a savings to the government. This benefit can be compared to the cost of applying a given suppressant. As agents differ in cost and effectiveness, we have developed a model that takes both of these factors into account. The cost benefit analysis that we performed compares the government's costs of applying dust suppression agents, at a fixed level of effectiveness, to the government's health care savings from the reduction in the number of hospital visits. The scope of our analysis is for a one-year period in Bangkok. We had to make a few educated assumptions to conduct our analysis, which are listed in Section 4.4. With an assumed number of kilometers of unpaved road in Bangkok and a specified percentage of the SPM being from these unpaved roads, maintaining a target level of effectiveness for a suppressant, over a year, allows a specific reduction in SPM for Bangkok to be calculated for the year. This reduced SPM level allowed us to make calculations of the approximate number of people who would not visit the hospital; this in turn allowed us to calculate the health care savings, or benefits, to the government.

As different agents do not have the same effectiveness, a different number of applications are required, per year, to maintain the target level of reduced SPM over that time. Thus, the costs of the agents were calculated for the number of times they would need to be applied, in the course of a year, to maintain a constant level of effectiveness. The cost per kilometer of each agent was determined first. This cost includes the cost of purchasing the material as well as labor and application costs. Those costs were then multiplied by the total number of kilometers of unpaved roads we assumed to exist in Bangkok. This gave us the cost for one application of each agent to all of Bangkok's unpaved roads. Multiplying these figures by the number of applications that each agent required to maintain the effectiveness level provided us with the total suppression costs to measure against the benefits.

In 1996, Maneerut Trakannuwatkul completed a thesis entitled Economic Analysis of Air Pollution and Health: A Case Study of Bangkok as part of his completion of a Master's of Economics degree in the Faculty of Economics at Thammasat University (40). The study directly relates the level of suspended particulate matter to total health costs; the individual acquiring medical attention and government subsidies contribute to the total cost. Our cost benefit analysis utilizes this study to find the estimated amount of money the government would save by a given reduction in the amount of SPM from treated unpaved roads per kilometer, for one year of dust suppressant use.

The most probable amount of people that get sick in one year from all respiratory diseases is found by multiplying Eq. 1 by the current population. In 1999,

$$\text{Probability of getting sick in one year} = \frac{3.745}{1+e^{-z}} \qquad \text{(Eq.1)}$$

the estimated population amounted to ten million people. In Eq. 1, z is an index that takes into consideration all factors that affect morbidity from respiratory illnesses. This is shown in Eq. 2, where SPM equals the average 24 hour suspended particulate matter level (in $\mu g/m^3$ x 100) over all districts recording pollution levels.

$$z = -2.87 + 0.0609 * SPM \qquad \text{(Eq. 2)}$$

In this equation we assume that other factors that affect respiratory related morbidity; such as lead levels, carbon monoxide levels, smoking and alcohol habits, etc., stay constant.

To find the amount of people that get sick specifically from suspended particulate matter we utilized safety levels composed by the World Health Organization. We assumed that the World Health Organization's maximum level of SPM is the level at which no one will get sick from SPM; the WHO established level is 0.12 $\mu g/m^3$. The percentage of people who get sick from SPM equals the value that Eq. 1 produces with the current SPM level subtracted by the value that Eq. 1 produces using the WHO's level for SPM.

To this point we have described the method by which the thesis predicts the percentage of people that become ill from SPM in the air, but we are interested in how many people no longer acquire medical care from a reduction in SPM levels. We do this by finding the amount of people who get sick from the current level of SPM (as described in the last paragraph) and subtracting the people who get sick from the new, reduced amount of SPM. This difference gives the estimated total amount of people who no longer require medical care in a year because of reductions in SPM.

Finally, we found the amount of money that the government would save in health expenditures from using a dust suppressant by multiplying the total number of people who no longer get sick in a year by the average amount that the government pays per person per year for such treatment. From the study's data on the economic treatment costs per patient in 1995 and the percentage of respiratory disease in-patients and outpatients, we calculated that the government on average pays 68 percent of total health costs. The economic thesis predicts the total costs for health care up to the year 2000, so we can take 68 percent of the value for 1999 and assume that to be the amount that the government would pay per person in that year.

3.2.6 Data Collection

In the Department of Environmental Engineering at Chulalongkorn University, specifically in the Soil Mechanics Research Laboratory, two graduate students devised a series of simulations to gather data about the effectiveness of various dust control agents. These two graduate students worked under the direction of Dr. Supot Teachavorasinskun, and the Thai Pollution Control Department funded the project. The team created three phases to observe the properties of the dust suppressants. The first phase imitated heat conditions to test water retention. The second phase simulated traffic loads on unpaved roads, testing the suppressants in a natural scenario. The final stage involved the application of dust control agents to an experimental road, but the results from this test were not available by the completion of this report.

3.2.6.1 Water Retention Experiment

The first stage of the dust suppression tests used intense lights to simulate the daily exposure of the sun on an unpaved road. The students aimed to gather information about each dust control agent's ability to retain water in the soil. Initially, the students used four dust control agents under the hot lights: calcium chloride, distillery waste, acrylic emulsions, and a polyvinyl acrylic emulsion (polymer) from the U.S.A. named Soil Sement. An electrical timer limited the artificial light exposure time on the treated soil samples. The fixed amount of daily exposure time mimicked the daily heat conditions on a road in Thailand. The lamps created a surface temperature of 50°C on the soil samples, producing comparable data for each tested suppressant.

The physical setup consisted of twelve bins of soil, each with a different dust control mixture applied topically. The soil used to test the dust control agents was the same type of soil utilized in road construction processes. Table 5 demonstrates the variables of the samples, and Figure 2 shows six bins from the setup of the experiment. Note that $CaCl_2$ represents the percentage of calcium chloride in a calcium chloride solution, Asphalt is short for asphalt emulsions, Polymers denotes the Soil Sement brand polymer, and D.W. stands for undiluted distillery waste. The colon notation, 1:3 for example, indicates the ratio of dust control agent to water.

Table 5: Concentrations/Application Rates of Agents for Water Retention Experiment

Untreated Soil	$CaCl_2$ 20% 2.5 l/m^2	$CaCl_2$ 30% 2.5 l/m^2	Asphalt 1:3 2.5 l/m^2	Asphalt 1:5 2.5 l/m^2	Asphalt 1:3 5.0 l/m^2
Polymer 1:7 2.5 l/m^2	Polymer 1:5 2.5 l/m^2	Polymer 1:3 2.5 l/m^2	D.W. 2.5 l/m^2	D.W. 5.0 l/m^2	Polymer 1:3 5.0 l/m^2

At pre-determined time intervals in the two month long experiment, the graduate students collected samples from each bin. The experimenters chiseled out portions of soil at 0, 1, 3, 7, 14 and 28 days after the setup of the experiment. The goal of taking these samples was to collect data about the agents' water retention abilities, as compared to that of the untreated section. To find the water content of the sample, they weighed the sample, placed it in an oven to evaporate the water, and then re-weighed it to find the dry weight. The difference of mass between the original sample and the dried sample yielded the water content in the sample. To ensure the continuity of the soil's surfaces with the agent, the removed soil was replaced by wax.

Figure 2: Water Retention Experimental Setup

3.2.6.2 Traffic Simulation

The students in the Soil Mechanics Research Laboratory devised another test to obtain data about how well the dust control agents keep dust on the road. The graduate students used a machine comprised of two rollers spinning on a circular bin of treated soil; see Figure 3 for a top view of the machine. The pressure of the rollers caused soil to loosen from the treated sample in the bin. The worn away soil moved to the inside and outside surface areas that the rollers did not cover, which allowed it to be collected and weighed at periodic intervals.

The rollers spun at 25 revolutions per minute at a radius of 21 centimeters, giving 2 kilometers per hour as the approximate speed. Scooping and weighing loose dust particles on the unrolled surfaces after the machine completed running provided the researchers with numerical data. Sweeping of the soil occurred at intervals of one hour, and the entire test lasted six hours. The final data reveals the overall amount of eroded dirt from each weighing.

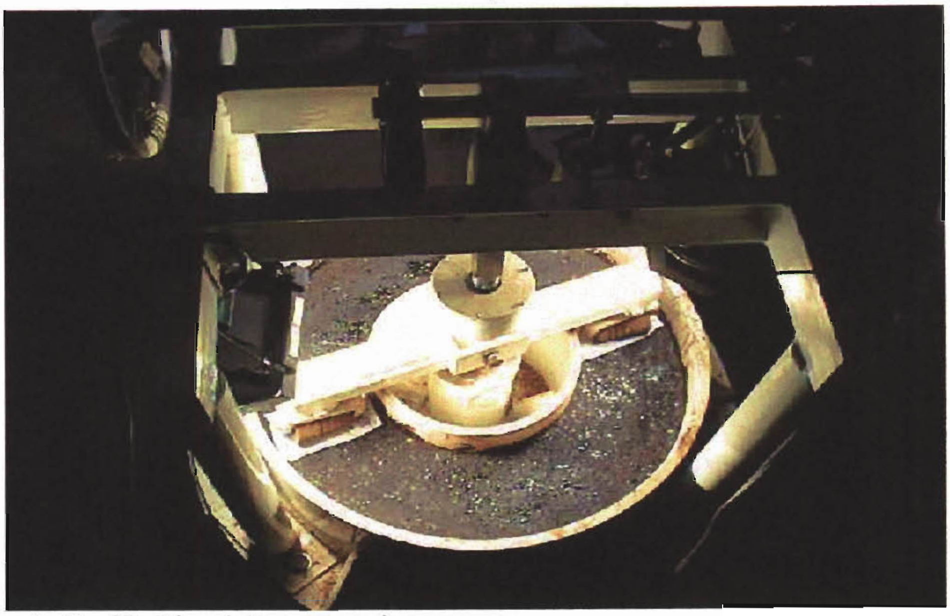

Figure 3: Traffic Simulation Experiment

3.2.7 Presentation/Roundtable Discussion

On February 23, 1999, we gave a presentation to representatives from various governmental agencies, private companies, and other parties interested in the topic of controlling dust on unpaved roads in Thailand. Our presentation focused on the research and information we had collected for potential dust suppression agents for Thailand to use on its unpaved roads. We also presented our methodology for cost benefit analysis. After our presentation there was a discussion period for all of the attendees. From this discussion we wanted to gain feedback about our project and a validation of our cost benefit analysis, as well as to obtain opinions about the assumptions we used in our analysis. Also, we developed a summary report of our presentation, translated into the Thai language, as a handout to the guests. This report can be viewed in Appendix B.

3.2.8 Recommendation Methodology

The overall goal of this project is to recommend the most suitable dust suppression agent for the use of unpaved roads in Thailand. This recommendation will come after we have carried out the previously mentioned methodologies and analyzed the resulting data. It is very likely that certain agents will be more suitable in different climatic conditions or environmental locations. For instance, calcium chloride may be the best agent in terms of availability or cost effectiveness, but lignin sulfonate may be the best solution from an environmental point of view. In order to evaluate these factors to make a final recommendation requires a careful act of balancing. Once all of our interviewing and data collection was complete, we made a summary chart comparing the suppression agents with the variables we are evaluating them by; this analysis will lead us to conclusions on what is feasible in Thailand.

Another part of our recommendation methodology was based on the results of our cost benefit analysis. Our cost benefit analysis will determine whether using a dust suppressant saves the government money when compared to the current method. As the costs of the suppressants are the primary factor in determining which one to use, especially with the current economic status of Asia, this analysis was crucial to make our final recommendations as it accounted for the cost effectiveness of the agents.

Chapter 4: Results

This chapter presents the relevant results that we received from conducting our methodologies. The first section provides the results that we obtained from our interviews. The second section presents the data that the graduate students in the Chulalongkorn Soil Mechanics Laboratory obtained from their water retention and soil erosion experiments. Lastly, we give a full account of the round table discussion that we chaired; this discussion involved many parties concerned with dust suppression in Thailand. From the results of this chapter, as well as from our research and cost benefit analysis, we conducted our analysis and developed our recommendations for Thailand's unpaved road dust suppression issues.

4.1 Interviews

Interviewing was our main method for gathering information. With some assistance from Dr. Supawan Tantayanon, our liaison at Chulalongkorn University, we were able to arrange interviews, overcome language restrictions, and achieve the goals established for each interview.

Our initial contact finding interview provided us with the names of relevant experts, producers, and an importer of dust suppression agents. In this session, Dr. Supawan introduced the project team to two environmental consultants, Dr. Sangsant Panich and Dr. Wongpun Limpaseni. These two gentlemen worked with government agencies and private companies in order to develop, specify, identify and implement environmentally safe industrial procedures. Their experience ensured that they knew of many of the people that we would want to talk to. Furthermore, this experience means that they were aware of the suppression agents that we proposed to study for use in Thailand, and were thus able to direct us to the correct sources of information. Dr. Supawan, Dr. Sangsant, and Dr. Wongpun specifically discussed issues related to government agencies and contractors, and provided information on polymers, sugar cane molasses, salts, distillery waste and asphalt emulsions.

4.1.1 Government Agencies/Standards

Thailand's government is a system of interrelated ministries and agencies. Within this structure, the ministries and agencies work on similar topics that are of major concern in Bangkok. The Pollution Control Department was cited as the main organization that would deal with the issue of dust control from unpaved roads. Upon our inquiries about the Bangkok Metropolitan Authority (BMA), an agency that our research had identified as important to our work, Dr. Sangsant suggested Dr. Noppaporn Panich as a good resource to question about government regulations concerning dust. At the time of the interview, she worked at Chulalongkorn University as an associate professor in the Environmental Research Institute, but previously Dr. Noppaporn consulted the Pollution Control Department, the main body concerned with airborne dust, on their drafts concerning dust control standards.

Dr. Noppaporn discussed tall building regulations concerning dust control that did not apply to unpaved roads, but still gave us an impression of what the government has done so far in the area of dust control. When constructing a tall building, a contractor must cover the sides of building with sheets to prevent airborne material from entering the atmosphere. At the construction site, workers clean truck wheels as vehicles are leaving; this keeps dirt and dust from being further spread. Also, the loads of the dump trucks need to be completely covered so that the contents do not fall out during transport. The government's goal with these regulations is to reduce the amount of pollutant material in the air to set standard levels.

The maximum amount of particulate matter in the air is included in the standards set by the Pollution Control Department. PM-10 levels should not rise above 0.33 mg/m^3 on a daily average, or above 0.1 mg/m^3 over a yearly average. The total amount of suspended particulate matter (TSP) levels are limited by regulations to 0.12 mg/m^3 per month and 0.05 mg/m^3 per year.

The set standards are not currently met in the metropolitan area of Bangkok. Dr. Noppaporn noted that the SPM levels are high because of the numerous construction activities undertaken in the city. The government runs these construction sites, but it is up to the individual contractor to decide upon the best time to spray water on the road. According to Dr. Noppaporn, and reiterated by many other people, the economic climate in Thailand makes the thought of purchasing dust control agents or any other additional expenses an unfavorable suggestion. Even the regular spraying of water that contractors currently use to adhere to the laws of dust suppression becomes a questionable expenditure under the poor economy.

4.1.2 Potential Products

In order to gain an idea of the feasibility of using dust suppression agents in Thailand, we had to interview the companies that are capable of providing such agents, or the people who would know about the potential use of such agents. The interviews that we conducted were of a potential polymer producer, an importer of salts, a sugar cane processing company, and an anonymous individual that who aware of the use of distillery waste.

4.1.2.1 Polymer Producers

The polymers that are suitable for dust suppression are called polyvinyl acrylic polymers. Many agencies in the United States have successfully used them as dust suppressants. In Thailand, Rohm and Haas Chemical (Thailand) Ltd. is the only company that produces these polyvinyl acrylic polymers. In the United States, the product sells under the name Acrylic BLM-MS and in Thailand as Primal AC 261.

Primal AC 261 is marketed as a paint additive and is not yet used to suppress dust on unpaved roads. The production facility, located in Chonburi approximately 100 km outside of Bangkok, has a production line devoted to making this material, and also has a second line available if a high demand arises for the polymer. The representatives quoted 40 baht per kilogram as the cost of the polymer, but this price would go down if the polymers were needed in large volumes. Representatives from Rohm and Haas did not provide information about the success that road maintenance departments had with the product in the United States, although references range from the Tennessee Valley Authority to the American Council for Reclamation Research.

To understand how Primal AC 261 works as a dust suppressant, knowledge of its formulation is essential. At the time of application, a worker slowly mixes the Primal AC 261 with texanol and water. Texanol is a member of the alcohol family with many other functional groups attached to it. The texanol evaporates from the emulsion at temperatures above 16° Celsius, causing the remaining polymers to bond together to form a thin film on the road. This film coats the dust, preventing it from becoming airborne, as it retains water in the soil enhancing stabilization. The producer's description notes polyvinyl acrylic emulsions for their adhesive abilities in paint and dust suppression on tennis courts. Given the application of the polymers on tennis courts, it argued that they should be suitable for use on unpaved roads as well. After the texanol evaporates, the remaining water penetrates into the soil creating a stable layer of dirt for vehicles to pass over.

According to Rohm and Haas representatives, any adverse environmental effects are associated with the texanol. The texanol quickly evaporates, however, leaving no damage to the environment surrounding the road. However, slight irritation occurs to skin and eyes if texanol is handled directly. Suggested polymer to water ratios are 1:8 to 1:10 by volume, making the polymer dilute to the point at which no health or odor problems are detectable. The polymer is not biodegradable, so it will be less likely to leach into the environment.

To apply the polymer, a tank truck is used to spray the emulsion onto the road. The Rohm and Haas representatives did not suggest spraying the polymer as a fine mist. The hotter the solution of polymer and texanol is, the better it will penetrate the road. Heated application is not required for dust control, but effectiveness increases with temperature. Rohm and Haas do not ship the texanol and polymer together, so responsibility for the mixing rests on site employees.

4.1.2.2 Salts

We interviewed two potential suppliers of salt. The first group imported magnesium chloride and calcium chloride from Israel. The second interview was with a member of the Ministry of Industry about a current project in central Thailand that will have copious amounts of disposable magnesium chloride solution in the year 2003.

4.1.2.2.1 Importer

In our initial contact finding interview, a discussion arose about the use of salts in Thailand. The magnesium chloride and calcium chloride produced at salt farms in Thailand are not of high quality, so Thais import much of these salts. Our interview was with a marketing manager, Kajorndej Sawangaroon, who represented Chemical Enterprises Company, LTD. and Thep Enterprises Company, LTD.

Importers ship calcium chloride and magnesium chloride once per month from Israel. The salts come in flake form in a thermosealed bag to keep moisture from dissolving the flakes. The cost of magnesium chloride is 12 to 15 baht per kilogram and the calcium chloride sells for 10 to 13 baht per kilogram. Other uses exist for these materials ranging from canned food additives to cement strengtheners.

Magnesium chloride works better than calcium chloride as a dust suppressant, according to the discussion at that meeting. An unpaved road worker should apply magnesium chloride at a rate of one kilogram per square meter. Reapplication occurs about once per week if no rain has fallen. The representative did not know of any unwelcome environmental side effects associated with either salt.

4.1.2.2.2 Ministry of Industry Project

During our round table discussion, we learned of a large-scale project being set up in central Thailand by the Ministry of Industry that would produce large amounts of magnesium chloride solution. We interviewed Dr. Anant Suwanapal, from the Ministry of Industry in the Department of Mineral Resources, to find out more about the project. The production facility is a collaborative effort between many countries of Southeast Asia to produce potash for fertilizer on a large scale. The place where the potash is to be mined is at Bamnet Narong in the Chayaboom province. A by-product of this mining is a 26% magnesium chloride solution by mass. When the plant is operational in 2003, it will have an annual production of 1.1 million tons of potash along with 5.0 million cubic meters of magnesium chloride solution. The ministry projects that production can continue at that rate for the next 100 years. Some uses for this magnesium chloride have been found, such as the production of magnesium oxide, which in turn is used to make magnesium metal. The ministry plans to sell some of the solution to the automotive industry, where they will use it in the production of alloy wheel rims. They also hope to incorporate the magnesium into fertilizers.

The many possible uses for the magnesium chloride do not account for all of the brine that will be produced at the Bamnet Narong mine. Dr. Anant welcomed the use of the magnesium chloride, as a dust suppressant because the 26% brine normally needs evaporation if it is to be used for other purposes. The absence of this process would save production costs because the magnesium is usually sold in the dry, flake form. Although the recommenced solution for dust suppression is 32%, the brine could be acquired very cheaply at 26%. The different solution levels may not require in a greater number of applications because of the small difference; if it does have a lower performance level, then only one or two more applications a year may be necessary. When we questioned Dr. Anant about the price of acquiring the magnesium chloride he said that he would need a better idea of how much solution we were interested in using. Only then would he be able to give us an estimate of the costs. He did assure us that no matter what the demand was, his price would be very competitive to our cheapest alternative.

Dr. Anant was very interested to hear about our use of magnesium chloride brine. When we asked him about any environmental harm that may be caused by the magnesium chloride he stated that the government would have no problems with the application as magnesium is considered to be a good fertilizer. He informed us that if we wanted to use the magnesium chloride for dust suppression purposes that the government would need to know the amount that we were interested in using. The government would also need to see proof that the magnesium chloride was indeed effective as a dust suppressant, and need documentation that it was used in the United States under approval of the Environmental Protection Agency.

4.1.2.3 Sugar Cane

We interviewed Theera Sanguandeekul, assistant managing director of Khon Kaen M.D.F Board Company, LTD., about his expertise in producing sugar. Our questions focused on the use of sugar beet extract (discussed in Section 2.4.3.2) as a potential dust suppressant, but in Thailand the nearest equivalent to sugar beets are sugar canes. Sugar beets do not grow well in Thailand, because they are suited to cooler climates. The sugar cane factory utilizes all parts of the sugar cane, including the waste, for a variety of purposes. Two of the more important purposes are for chemical fertilizer and fiberboard. The high demand for this waste creates a low availability and high cost. Therefore, sugar cane extract is not an appealing agent for dust suppression in Thailand.

Another of the by-products of sugar cane processing that has the potential to be used as a dust suppression agent is molasses. Mr. Sanguandeekul informed us that this molasses is used for producing ethyl alcohol, which in turn leads to distillery waste.

4.1.2.4 Distillery Waste

An anonymous source in Ubon Ratchathani was able to provide us with some general information pertaining to the use of distillery waste on unpaved roads. Apparently, truck drivers from the distillery plant will spray the distillery waste over an unpaved road surface for 50 baht. This money is paid from a collection of local residents that live in close proximity to the road being covers. Our source informed us that one truck, containing 15 cubic meters of the agent, covers approximately 500 meters of roadway approximately 6 meters wide. Also, this suppression agent was said to last two weeks, without rain, before reapplication is required. As the residents wanted the distillery waste to continue being sprayed, the interviewee assumed that the distillery waste did not cause any immediate environmental damage.

4.1.3 Experts

We interviewed several experts in fields relevant to our dust suppression project. One expert was a water and environmental consultant, who is familiar with distillery waste. Another was a professor of civil engineering at Chulalongkorn University. Lastly, we interviewed the Assistant Dean for Research and Information at the College of Public Health at Chulalongkorn University.

4.1.3.1 Environmental/Water Consultant

In order for us to learn about the potential of using distillery waste to suppress dust on unpaved roads, we interviewed Dr. Suchint Phanapavudhikul, the managing director of Water & Environment Consultant Corp., Ltd. In our interview, Dr. Suchint provided us with a report he had written entitled "Utilization of Spent Wash Liquor in Paddy Fields" from January 25, 1999. In this report, Dr. Suchint claims that spent wash liquor (distillery waste) has increased the rice yield of paddy fields in the Ubonratchathani Province by 2 to 3 times. This is a very inexpensive method for the factory to dispose of its distillery waste, while providing a valuable resource to nearby farmers. However, another means for the distillery waste is to use it as road spray, in other words, a dust suppressing agent. As this product is a waste material, the distillery plant may provide it at a low cost. In addition, using the waste as organic fertilizer shows that the agent is not immediately environmentally harmful to land.

4.1.3.2 Civil Engineer

As a professor of civil engineering at Chulalongkorn University, Dr. Supot Teachavorasinskun was familiar with possible dust suppression agents for use in Thailand. Dr. Supot cited many of the problems that exist in Thailand. Over 10,000 kilometers of roads are unpaved in Thailand, most of which are not treated with water or any other method of dust control. Many temporary roads stay that way for years. Until recently, the government had no plans to control dust on unpaved roads. The tests done in the Soil Mechanics Laboratory (described in Section 3.2.6) were among of the first steps to help determine the best suppression agent for long-term unpaved roads. The government has advocated faster construction to keep sections of road unpaved for the shortest amount of time possible (discussed further in Section 4.1.4). Dr. Supot suggested that if a road were to stay unpaved for more than a month, then a road stabilizer would be necessary. Otherwise, the use of water would continue for the shorter time periods. Dr. Supot thought that the government would not tend to limit what contractors used on roads since the agents would keep people happy and require less maintenance on roads.

The best road material stabilizers for unpaved roads, in Dr. Supot's opinion, are asphalt emulsions. Concrete roads are possibly the best option overall in his opinion, but they are expensive to construct. The cost of raw materials favors asphalt emulsions at 10 baht per liter compared to 140 baht for a liter of base polymer material. In addition, the asphalt mixture would last several months to years, whereas the polymer would need multiple applications every year. The two dust suppressing agents coat the road, preventing particulate material from lifting off the road, but asphalt also penetrates into the road bonding the underlying soil together.

Asphalt emulsions consist of asphalt mixed with water to a point at which the asphalt can be sprayed onto a road. The resultant material remains thick, so that it sticks to dirt and the inside of a spray truck, causing special trucks to be set aside for the spraying of the material. Most distributors of asphalt emulsions should have their own spray truck to transport the material to site. Due to the high content of dihydrogen oxide at emulsification, heavy rains could wash away a significant portion of the applied asphalt emulsion. Thus the only necessary reapplication of this dust suppressant may occur after the rainy season.

Despite the erosion of the emulsion, no reports of oil runoff have been noted. Although some material is washed out of the road, a nearby citizen should never find oil in the runoff because it is made with petroleum resins rather than oil. The asphalt emulsion is similar to the asphalt used in paving roads, so environmental effects are minimal.

4.1.3.3 Public Health Expert

We interviewed Dr. Nuntavarn Vichit-Vadakan, Assistant Dean for Research and Information in the College of Public Health at Chulalongkorn University, about her expertise in the field of public health. From the discussions that developed, we were able to gain insight into many topics that included hospital costs, health insurance schemes, and health effects from PM-10.

Specifically, we talked about the compounding effects from air quality and the difference between chronic and acute illnesses. Dr. Nuntavarn informed us of the research she had done on the acute effects of poor air quality. The study, undertaken by the Pollution Control Department (PCD), was mainly conducted to gain a better understanding of Bangkok's air pollution problems. From this understanding the PCD hoped to develop an air quality management strategy and a cost effective strategy for reducing levels of particulate matter, with demonstrated health impacts. To determine if illnesses, such as the flu and colds, were a result of the same day or the previous days' pollution levels, tests were done measuring the air quality by a moving average of 3 or 5 days, and the researchers determined that the effects of air pollution could be felt within 5 days. Dr. Nuntavarn also mentioned that the same dose response was found in studies that were done in São Paulo, Brazil and Utah in the United States. Apparently, no reports have been done on chronic illnesses caused by air pollution in Bangkok. In addition to the studies on health effects from particulate matter that we were already aware of, Dr. Nuntavarn informed us that new studies have shown effects on heart rates as well.

4.1.4 Civil Engineering Company/Contractor

The Civil Engineering Company, LTD., holds several government contracts to build dams, buildings, and roads. One of their employees, deputy managing director Komol Pinyosukhee, talked with us about roadway construction and the expenses associated with it.

The Thai government owns most of Bangkok's metropolitan area construction projects. The highway construction occurs in five hundred-meter sections and about ten days are required to complete each section. The roads are built in five layers, so the road surface is constantly rising during the ten-day period. Road site employees work at night to minimize traffic congestion during the day. Unfortunately, the overloaded daily congestion means that unpaved roads need to stay open to vehicles during the day. Water trucks spray two to three times a day in an attempt to keep loose materials on the road. A helper utilizes a high-pressure hose to spray all lanes of traffic in one pass. The contractor makes the decision of when to spray the road with water based on weather conditions, so no statistics exist on the frequency of application.

To operate the truck, the construction company must pay for the costs of owning the truck, of employing a driver and helper, and of fuel. Owning a truck costs this company 40,000 baht per month. The water truck has no other functions and operates for 24 working days per month. To employ the two man crew on the truck costs about 14,000 baht per month. Approximately 40 liters of diesel fuel per day are consumed by the truck at a gas price of 7.5 baht per liter. The water is free because truck drivers pump the water out of the river or canal, and any other costs of transporting the water are categorized under labor or operation costs.

Outside the city, road construction takes place in 5-kilometer sections. New roads or expansion lanes close to traffic during the construction process. Instead of a ministry in the government, local highway departments under the direction of a district governor manage non-highway projects. In small villages, the road may be paved inside the main part of the village to reduce dust, but outside of the town the road may be left as a dirt road.

Mr. Komol did not express enthusiasm for using dust suppression agents other than water. He thought that chemicals were too expensive even though the government pays for the construction of the road. Moreover, the acquisition and handling of materials requires more administration for the project.

4.2 Experimental Data

The graduate students at the Soil Mechanics Laboratory at Chulalongkorn University performed two types of experiments with some of the suppressants that we were studying. As described in Section 3.2.6.1, they did an experiment looking into the water retention capabilities of polymers, calcium chloride, asphalt emulsions and distillery waste. The second experiment that they performed is called a surface bulk loading experiment, which simulated traffic passing over soil with a dust suppressant applied to it. In this section we will present the results obtained from both experiments.

4.2.1 Water Retention Experiment

The two graduate students monitored the water content of the soil samples over the course of 28 days and from this were able to generate a graph that presents their results. The data shows what the most effective agent is, as well as the best dilution and application rate to use. The data is particularly useful for our project as it was obtained under the climatic conditions of Thailand. All of these issues are incorporated into our analysis in determining which is the most suitable agent for use in Thailand.

Figure 4 shows how the water content of the soil varied over the course of the 28 days. Water content measurements were taken at 0, 1, 3, 7, 14 and 28 days. The graph shows that in general the water content of the soil decreases as the length of exposure to the hot lamps increases. The agents differ greatly, however, in the rate at which this decrease occurs. An application of polymers in a 1:3 dilution at 5.0 l/m^2 is best at retaining water, as it still has a water content of 5.83% after the 28 day period, as opposed to the control experiment which only has 3.06% water left. It is interesting to note that the three different polymer dilutions, namely 1:3, 1:5, and 1:7, are all equally effective with just under 4.0% water content remaining. We had hoped to have data about the use of distillery waste; although the experiment was initially set up to obtain this, the final report that we were provided did not include distillery waste.

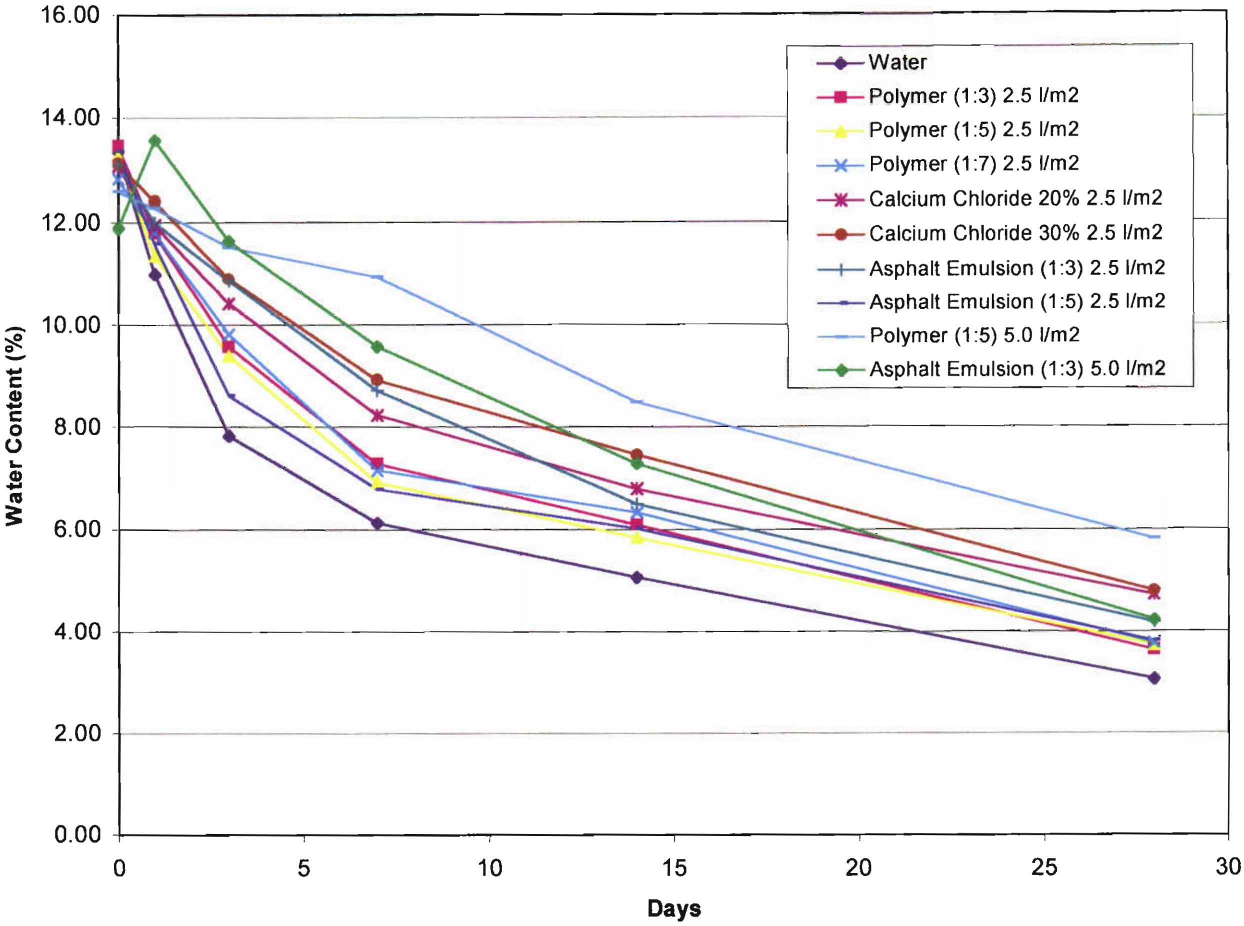

Figure 4: Water Retention Results
Soil Mechanics Laboratory, Chulalongkorn University
Bangkok, Thailand, February 1999

4.2.2 Traffic Simulation Experiment

The students in the Soil Mechanics Laboratory performed five traffic simulation tests as described in Section 3.2.6.2. These tests included a control experiment and two runs of polymers and asphalt emulsions. The two runs differed by having different application rates. In these experiments they would run the rollers over the soil and at fixed intervals of time collect the soil that had eroded off of the surface. With this data, they were able to generate a graph that showed the amount of soil that was worn off as a function of time; this graph is shown in Figure 5.

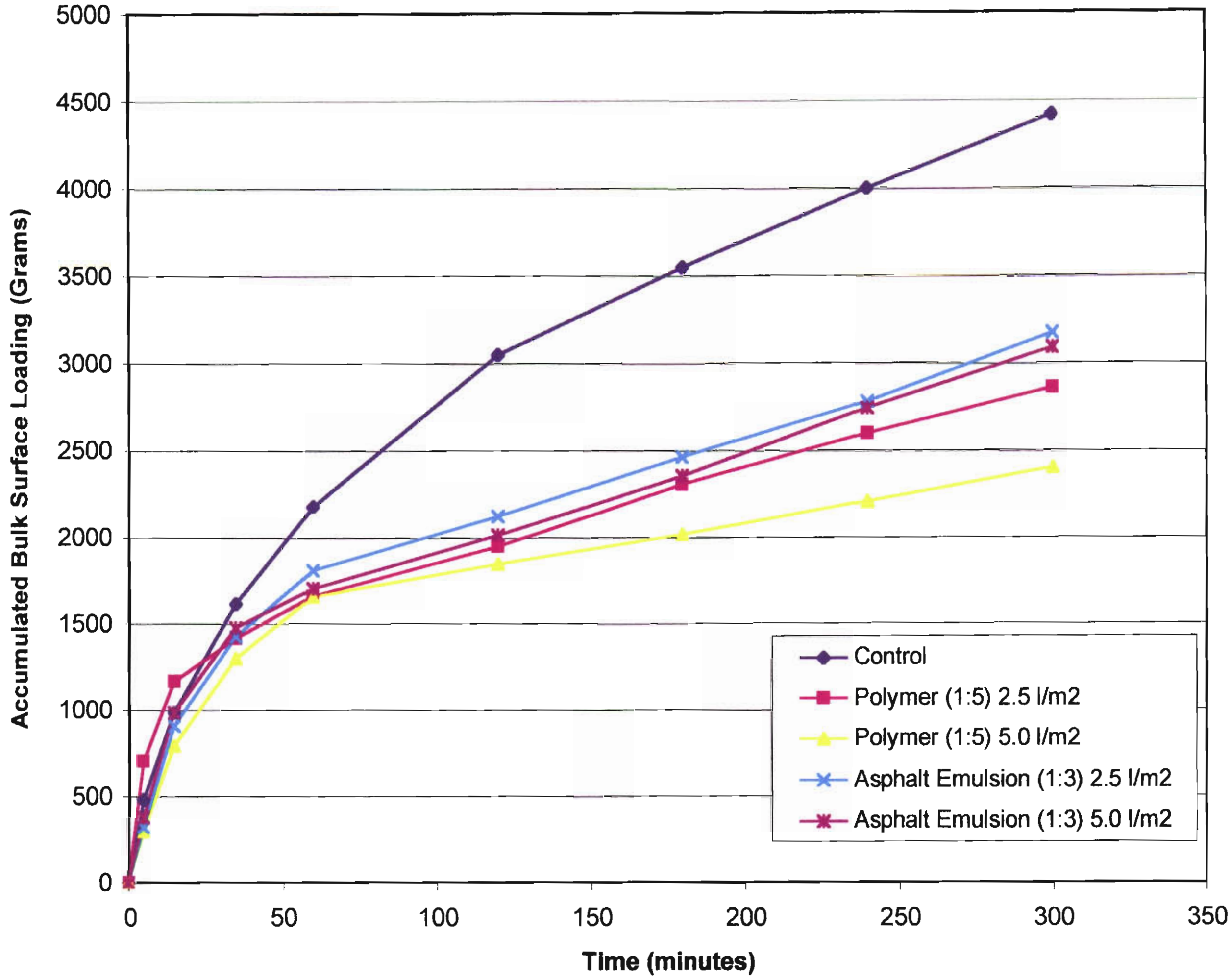

Figure 5: Traffic Simulation Results
Soil Mechanics Laboratory, Chulalongkorn University
Bangkok, Thailand, February 1999

The results from this experiment provided us with useful data about the durability of a given dust suppressant. The more durable an agent is, the more effective it is going to be, which is something that needs to be taken into consideration for the cost effectiveness. The more durable a suppressant, the less soil it is going to allow to erode over a given period of time. So from the graph it can be seen that either of the polymer emulsions are a better road stabilizer than the asphalt emulsions as they retain more soil. Specifically the polymers diluted 1:5 and applied at 5.0 l/m^2 allowed 2,409 grams of soil to be worn away over the course of the six-hour experiment. This value can be compared to the 4,425 grams of soil wore away in the control experiment over the same length of time.

4.3 Presentation/Round Table Discussion

On February 23, 1999, we presented our findings to many parties concerned with dust suppression in Thailand. After our presentation we engaged in a discussion about issues related to the topic. Dr. Sangsant Panich moderated the meeting, attended by members of the pollution control department, salt producers and importers, Dr. Wongpun Limpaseni, Dr. Nappaporn Panich, Dr. Supawan Tantayanon, and Dr. Richard Vaz. In this meeting we presented our initial findings concerning possible dust suppression agents. The findings that we presented were based on what we knew about availability in Thailand, environmental impact, cost, and effectiveness. We also presented the cost benefit analysis that we had developed. As a result of our presentation we asked for feedback on what we said as well the analysis that we had carried out. We received minimal feedback on our analysis from those present, although they did refine a few of our assumptions. Dr. Noppaporn informed us that it was not accurate to consider that water was free, especially in Bangkok, in the dry season. Dr. Sangsant informed us that a more realistic approximation for the width of an unpaved road was six meters, as this allowed for one lane of traffic in each direction. We were also informed that our cost benefit analysis may be more applicable to Chiang Mai where the dust problems are four times worse than those in Bangkok. We learned from one of the salt experts present that although the magnesium from Mahasarakham may be free, it was not an economically realistic option as so little was produced.

After our presentation, the floor was opened up to a discussion about the dust suppression problem in Thailand. The aim of this discussion was to evaluate the feasibility of implementing dust suppression agents. In order to evaluate this, both prices and availability were the main topics of discussion. As much of the conversation was carried out in the Thai language, we were unable to understand what topics were being discussed. However, there were times when English was used, and mainly salts and polymers were discussed. There was little need to discuss the use of asphalt emulsions as the necessary products are already produced and supplied in Thailand.

There were several representatives from the salt industry present, so a wide variety of information was exchanged about this alternative. The experts believed that the price of obtaining magnesium, as well as calcium chloride, would drop significantly in the future. At first, they believed that the potential for production of either of these two salts in Thailand was minimal. The main reason for this was that the salt deposits in Udon Thani were predominantly potassium or sodium chloride with only traces of magnesium chloride. Aside from that, calcium chloride is not usually found naturally and needs to be made from a chemical reaction. It was also believed that the small-scale production of calcium and magnesium chloride was too expensive. A lot of this expense was attributed to the high-energy tariffs that the government was imposing. It was said that to stimulate domestic production to make these salts more available, the government may want to examine an energy subsidy for these industries. At that point the topic changed to discussing whether or not the supply of salt was sufficient to meet demand. Many were shocked when they learned that each square meter of unpaved road needs about five kilograms of salt in solution every year to effectively suppress dust. They were worried that the demand for the salt would easily outstrip its supply, making availability more of a problem than cost.

During the discussion of supply and demand, one member of the floor spoke about an ASEAN potash project that is being set up at present in Thailand. The relevance of this project is that one of its by-products is a magnesium chloride solution. This person believed that the solution could be obtained at a fairly low price and in a large quantity to treat many roads. The project was currently being implemented and would be fully operational in 2003.

The possibility of using polymers in Thailand was also discussed. The consensus was that there was no possibility of actually producing the correct type of polymers in Thailand. The polymers that are necessary for dust suppression are difficult to produce, making it unlikely that producing them in Thailand is feasible as the domestic market is not sufficient. At present, Rohm and Haas in Chonburi do supply the correct polymers, but they import the base materials and merely mix them for the required applications. A great concern was expressed that Rohm and Haas may work themselves into a monopoly position, thereby driving the price of polymers very high. To prevent this monopoly it was thought that possibly other importers and mixers should be looked into.

As the main problem with polymer production was found to be the lack of a market, ways of creating markets were discussed. It was believed that making use of dust suppression agents a government regulation could create a market for them. If municipalities must use the agents, they will be forced to purchase them. Aside from creating a market using government regulations in Thailand, the possibility of creating new markets in neighboring countries was also discussed. If Thailand could show that dust suppression has economic benefits, then other countries could pass regulations thereby widening the customer base for the Thai initiative. Dr. Sangsant summed up the discussion of producing polymers in Thailand by saying "it all comes down to economies of scale."

In conclusion, it was thought that municipalities should use some dust suppressants on a demonstration basis. Based on the results of that, a decision could be made for more widespread implementation. It was furthermore decided that the government should look into providing tax relief on the imports of raw materials used for dust suppression. This would make dust suppression cheaper and more feasible for Thailand in the short term.

4.4 Cost-Benefit Analysis

The methodology that we used to determine whether or not using dust suppression agents was economically feasible was described in Section 3.2.5. In that section, we stated that our model made use of some educated assumptions. These assumptions are as follows:

- Population of Bangkok: 10,000,000
- Present level of SPM in the air is 0.3 mg/m^3
- 5 % of SPM in the air is from unpaved roads
- Number of re-applications of the agent will maintain a 90% effectiveness level over the course of a year
- Unpaved roads are 6 m wide
- There are 250 km of unpaved roads in the Greater Bangkok area
- No suppressants are applied during the 3 month rainy season

Given these assumptions and the model that we based our benefit on, we were able to generate Table 6. This table completely outlines our cost benefit analysis by calculating the costs of applying the agents and the monetary value of the resulting reduction of hospital visits. Using our material cost, we computed the total cost in baht/km to apply each agent. This number is multiplied by the total number of unpaved roads in Bangkok, and then divided into the government health care savings from the specified reduction to determine the number of applications that would result in zero costs or savings. Thus, if a given agent requires more applications than its break even number to maintain the effectiveness level, it will result in expenditure. The steps we used to obtain this data are shown in Table 6.

Table 6: Cost Benefit Analysis Worksheet

Improved air quality calculation:			
Initial SPM Level 24 hour average (mg/m^3):	0.3		
Percentage of dust specifically due to unpaved roads:	5%		
Dust suppression reduction:	90%		
Overall Reduction in SPM:	4.5%		
Reduced SPM level after suppression (mg/m^3):	**0.2865**		
Effect of air quality change on number of hospital visits:			
Population of Bangkok:	10,000,000		
Probability of Getting Sick at WHO levels:	0.214		
Probability of Getting Sick In a Year Without Reduction:	0.238		
Number of people who get medical treatment at current level:		2,376,833	
Probability of Getting Sick In a Year With Reduction:	0.236		
Number of people who get medical treatment at reduced level:		2,358,598	
Overall Percent Reduction (%):	0.182		
Number of fewer illnesses due to reduction (patients/year):	**18,235**		
Government contribution to health care costs:			
Total projected health expenditure in 1999 (baht):	3,574,190,000		
Percentage of total that is subsidized by government:	68%		
Government health care subsidies in 1999 (baht):	2,443,024,766		
Government subsidy per patient in 1999 (baht/patient/year):	**3,174**		
Monetary impact of air quality improvement:			
Total reduction in government health subsidies (baht):	**57,882,560**		
Assumed kilometers of unpaved roads in Bangkok (km):	250		
Amount saved per kilometer of unpaved road (baht/km):	**231,530**		

	Material ($baht/m^2$)	1 km = $6000m^2$		Application costs		
$CaCl_2$	15.0		Tank truck =	360,000 baht/yr		
$MgCl_2$	14.6		Labor =	126,000 baht/yr		
Polymer	2.8		Diesel =	64, 800 baht/yr		
Asphalt	4.2		**Total**	**550,800 baht/yr**		

					Health Care Savings (baht):	***57,882,560***
Agents	cost for one kilometer	cost for one application	Limited applications	required applications	total cost applications/year	**savings**
	(baht/km)	(baht)	(applications/year)	(applications/yr)	(baht/yr)	**(baht)**
$CaCl_2$	90,000	22,500,000	2.57	6	135,550,800	**(77,668,240)**
$MgCl_2$	87,660	21,915,000	2.64	6	132,040,800	**(74,158,240)**
Polymer	16,860	4,215,000	13.73	8	34,270,800	**23,611,760**
Asphalt	25,080	6,270,000	9.23	9	56,980,800	**901,760**

Our analysis shows that the government would save money from the application of polymers or asphalt emulsions, but using either of the salts would result in an overall expenditure. The government savings in health care subsidies are 57,882,560 baht for the 4.5% reduction in SPM. Subtracting the total cost of application for each agent results in the subsequent savings of 23,611,760 baht for the polymers and 901,760 baht for the asphalt emulsions. Using magnesium chloride results in an expenditure to the government of 74,158,240 baht, while calcium chloride's net cost to the government is (-) 77,668,240 baht.

Chapter 5: Analysis

We have lived in Thailand for almost two months and have experienced the air pollution problem first hand, especially in Bangkok. As previously stated in this report, serious health implications have been directly linked to SPM. As the Thai government has spent millions of baht in recent years to study the problem of air pollution and the health effects from it, they are aware of the importance of reducing this pollution. There are many contributing factors that account for the current levels of air pollution in Bangkok and in Thailand. Each of these sources of SPM requires a different method to reduce its contribution. For the purpose of this project, we are looking into reducing the SPM levels in the air by lowering the amount of dust becoming airborne from unpaved roads.

Many of the unpaved roads in Bangkok are temporary roads that are created during large-scale construction/transportation projects. As the government owns most of these projects, they would bear the costs of using dust-suppressing agents other than water. However, there are many benefits to be gained from the use of these agents. The most important benefit is the improved health of society. There is also an economic benefit to the population as well as to the government from reduced hospital visits. Economic benefit also exists in terms of reduced maintenance of unpaved roads and the vehicles that travel over them. There are also environmental benefits from reducing SPM, particularly to vegetation. Lastly, there is no price easily associated with reduction of pain and suffering, but this may be the most significant long-term benefit of all. Aside from the reduced expenditure in health care by the government from the fewer hospital visits, all of the benefits are obtained at no additional cost to the recipient.

5.1 Summary of Agents

Based on the literature review and interviews that we conducted, we were able to devise Table 7. This table summarizes all of the agents that we researched and incorporates relevant information about them.

Table 7: Comparisons Between Dust Suppression Agents

	Material Cost (baht/m^2)	Available in Thailand	Environmental Harm	Application
Calcium Chloride	15.00	Yes	Potential	Easy
Magnesium Chloride	14.61/low cost*	Yes	Potential	Easy
Polymers	2.81	Yes	None	Easy
Asphalt Emulsions	1.88	Yes	None	Separate Truck
Distillery Waste	Free	Yes	?	Easy
Soy Bean By-product	?	?	None	Heated
Lignin Sulfonate	?	?	None	Difficult
Sugar Beet/Cane Extract	?	No	None	?

* Waste product of salt farming in Mahasarakham and by-product of potash mining in Bamnet Narong

The first column lists the costs of obtaining each suppressant material for use on one square meter of road. This takes into account the application rate of the agent and cost of purchasing the material, but does not include the costs of application or take into consideration rates of re-application; these factors will be included in our subsequent analysis. The second column lists whether or not the agent is available in Thailand. The "?" in this column denotes that we were unable to obtain any information about the availability; it is possible that lignin sulfonate and soybean oil by-product are available in Thailand. The third column is an environmental evaluation based on our present knowledge, as many of the agents have not been tested for impacts from use as a dust suppressant. The "?" for distillery waste is an indicator that we are not aware of the environmental harm of this product because not enough research has been done on it. The fourth column evaluates the ease of application. An easy application involves the use of a spray truck to apply the agent to the road. The "?" for sugar beet extract indicates that we do not know how this agent is applied. Analyzing the information in Table 7 allows three of the agents to be excluded from further analysis. Due to the lack of information about lignin sulfonate and soybean oil by-product it was not possible for us to evaluate these agents any further. Any analysis performed without a price or indication of availability would be meaningless. The unavailability of the sugar beets in Thailand forced us to cease its evaluation at this stage. The exclusion of these three left five agents that we decided to evaluate further.

5.2 Feasible Agents for Thailand

Now that we have limited the number of agents feasible for use in Thailand, our analysis looks further into each of those agents. After our initial analysis we devised Table 8 to analyze the five most feasible agents for use in Thailand; they are the calcium and magnesium chloride, the polymer and asphalt emulsions, and distillery waste.

Table 8: Feasible Agents for use in Thailand

	Effectiveness In Rainy Season	Best Usable Location	Effectiveness
Magnesium Chloride	Poor	Central/South/ North East	Best
Calcium Chloride	Poor	Central/South	Very good
Polymers Emulsions	Good	Central/South	Good
Asphalt Emulsions	Good	Near oil refinery	Good
Distillery Waste	Poor	Near distillery	?

Based on studies done in the Soil Mechanics Laboratory at Chulalongkorn University, the United States, Germany, and Australia, we have rated the effectiveness of each of the feasible dust suppression agents. In these studies the salts showed the best effectiveness, followed closely by polymers and asphalt emulsions. Studies also show that the magnesium salt performs slightly better than calcium chloride. Limited comparative data exists on distillery waste, so no ranking can be given to that agent. In considering our rating we must keep in mind that rainfall, humidity, and temperature are key factors that determine how well the agents will perform. The humidity and temperature factors for the test done at Chulalongkorn best represent the conditions for Thailand.

The salts are not very effective in the rainy season due to their water soluble characteristics. Also, it is in this season that runoff is of most concern, and runoff from salt has the potential to cause more of an impact than the other agents. Distillery waste should not be mixed with the regular water supply, so the waste should be stored during the rainy season. This storage is necessary because distillery waste has a very high biological oxygen demand (BOD), namely that of 30,000-40,000 mg/l, that would rapidly deplete the water of all oxygen needed by fish and other animals.

Finally, transportation costs must be included when considering what agent to apply. If a province is in the northeast and contains a distillery, then transporting polymers from Chonburi may not be the best option. In Table 8 we list what area would be best for each type of suppressant due to the potential costs associated with transporting the material across the country. Distributors import salts to Bangkok and manufactures blend polymers in Chonburi, which are both in the central region. Their location suggests that use of their suppressants would be best in the central and southern region. Magnesium chloride is also being discarded at the salt farms in the northeast; this salt could be used on an unpaved road instead of put in refuse piles however amounts are limited. Refineries and distilleries are located in various locations throughout Thailand. Municipalities located near a distillery or refinery may choose to use the products of these factories to control dust in their district.

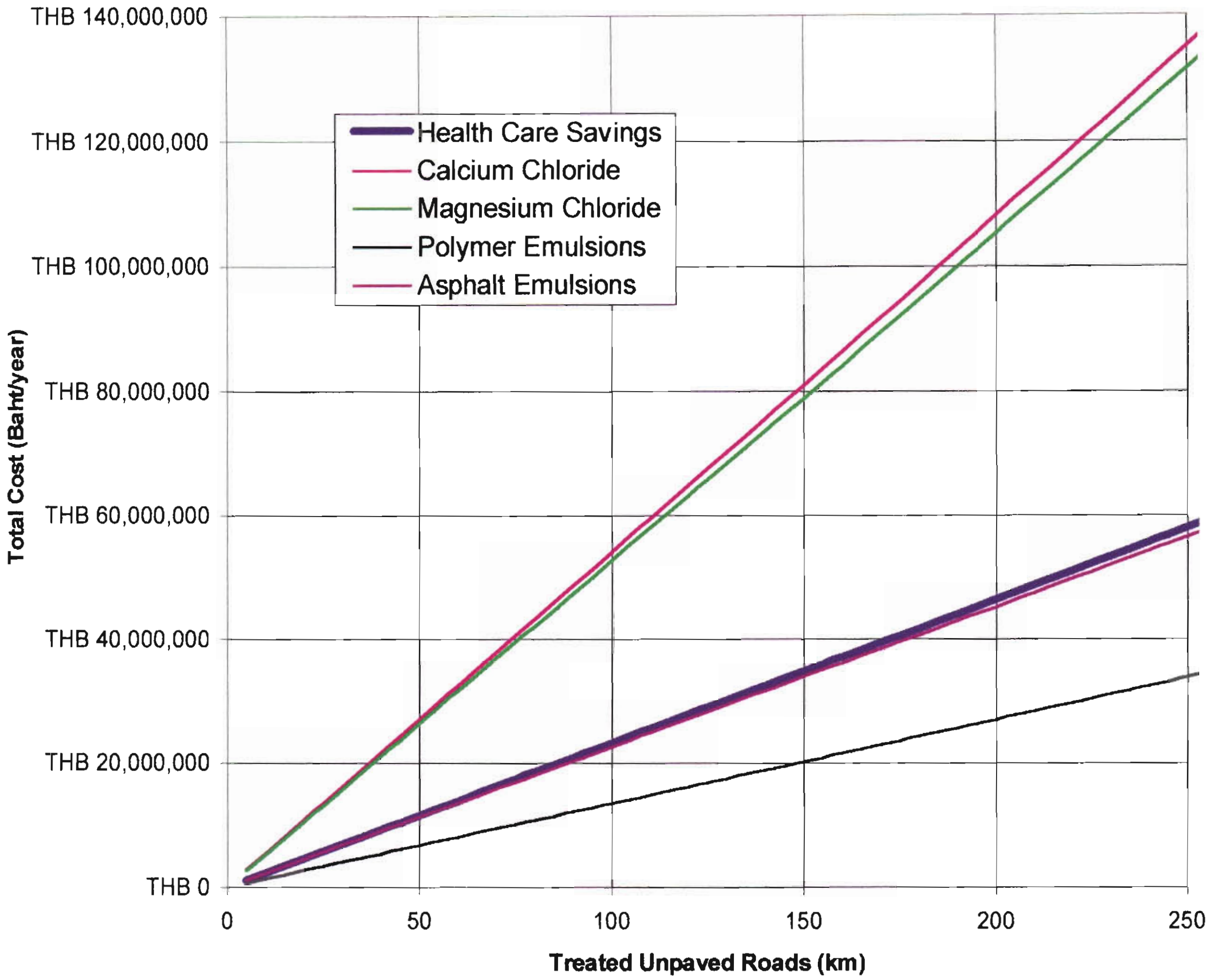

Figure 6: Results of Cost Benefit Analysis

5.3 Cost Benefit Analysis

Based on the spreadsheet in Table 6, we developed the graph shown in Figure 6. The y-axis represents costs and savings to the government over one year. The x-axis represents the assumed 250 kilometers of unpaved roads in Bangkok. The thick blue line shows the health care savings the government would achieve as a result of maintaining a 4.5% reduction of the current SPM levels over a year. The thin lines represent the costs to the government for applying the agents over all 250 km of roads necessary to achieve the 4.5% reduction level. As the figure shows, it will cost significantly more to use salts than it would to use polymers and asphalt emulsions. The most important feature of the figure is that the government will save more in health care reduction from using the polymer or asphalt emulsions in one year than they would spend to apply them over that same year.

There is an important aspect associated with our cost benefit analysis that is not seen in the actual analysis. We have considered all of the costs associated with using the potential dust suppression agents, but we have only considered the direct monetary benefits to the government in terms of reduced health care subsidies. As we have previously explained, there are a number of other benefits which will accrue, free of charge, to society as a result of reducing the SPM in the air of Bangkok. Thus, the overall benefits are greater in each case, and may justify the use of any of the possible suppressants. Ultimately, the choice of suppressant will be based on practical considerations including location, climate, and availability; however, this analysis suggests that in any case the use of these suppressants can be justified.

Chapter 6: Conclusions

Based on our research, interviews, analysis, and the time we have spent in Thailand, we have developed the following set of conclusions. These conclusions have been logically devised from the material that was presented in the first five chapters of this report.

1. **Thailand has a severe air pollution problem in which dust from unpaved roads is a contributor.** Newspaper articles, expert reports, and personal plights exemplify the existence of many problems with air pollution and dust form unpaved roads.
2. **There are many benefits associated with reducing the current levels of SPM.** The population of Thailand will greatly benefit from the reduction of dust in the air. The Economic Analysis of Air Pollution and Health completed in 1996 creates a model for predicting some of the costs associated with suspended particulate matter. In addition to the monetary benefits, Thais will also gain intangible benefits from not being sick as often. Aside from that, a reduction in the amount of SPM in the air will have aesthetic benefits as well, since particulate matter settles out of the air and onto everything.
3. **Using dust-suppressing agents other than water will reduce current SPM levels.** Numerous studies conclude the high level of effectiveness of alternate forms of dust suppression. Water is effective for a very short amount of time, and reapplication will rarely occur as often as necessary. Water also leaves the road in a worse condition than prior to application. Research done in the United States, Germany, and Australia conclusively demonstrates that all the dust suppression agents discussed in this report effectively control dust from unpaved roads.

4. **The government has the potential to save money from the application of such suppressants.** The government subsidizes health care, including respiratory cases associated with high levels of suspended particulate matter. The government savings in health care subsidies outweigh the costs of applying the polymer and asphalt emulsions. In 2003, the use of magnesium chloride may also become economically viable when the by-product of the Bamnet Narong potash project becomes available.
5. **Any expenditure that is made in applying dust suppressants is a worth while investment for society.** Although some agents cost more than the direct government savings in health care subsidies, the use of dust suppressants provides other benefits to Thailand and its citizens, including lower health care costs, lower road construction costs, improvements in air quality, and better living conditions.
6. **Using dust-suppressing agents other than water is feasible for Thailand in the near future.** Materials, equipment, and labor are readily available for dust suppression use in Thailand. The transition from using water to better suppressants will be easy, as the techniques and equipment for application are the same. The only factors that are preventing the use these agents are associated with cost; these costs have been clearly justified.
7. **Polymers and asphalt emulsions are the most cost-effective and environmentally friendly agents for Thailand.** Salts and distillery waste have questionable environmental impacts to local lands, leaving polymers and asphalt emulsions as the most suitable agents readily available in Thailand. Both polymer and asphalt emulsions will save money for the government according to our cost benefit analysis.

8. **Polymers and asphalt emulsions are also the most readily available agents in Thailand at present.** Any oil refinery in Thailand has the materials necessary to make asphalt emulsions for use on unpaved roads. Rohm and Haas in Chonburi are able to supply the polymers for mixing into the emulsion.
9. **Importing calcium and magnesium chloride is not cost effective at present.** These imported salts come in flake form to Thailand at a relatively high price. The amount of salts needed to cover a significant amount of roads is not a wise investment as better options are available.
10. **Distillery waste has the potential to be a useful agent in Thailand.** This agent has not been tested for specific data in relation to dust suppression. Once this has been done, feasibility will be more easily determined.
11. **In 2003, a large supply of magnesium chloride will be available in Thailand for use on unpaved roads.** One of the important considerations in the potash project is its proximity to a railroad. This could allow for a more widespread use of the salt, or allow it to be transported to the locations that have a greater need for dust suppression.
12. **Sugar beet extract is not a suitable agent for Thailand.** The climate does not allow for the growth of sugar beets.
13. **Lignin and soy bean oil by-product may be feasible agents for Thailand.** We were not able to gather enough information to claim these agents are suitable, nor to exclude them from the list of potential agents.

Chapter 7: Recommendations

We have developed the following recommendations for Thailand according to the goals of our project.

1. **We advise the Thai government to implement regulations requiring the use of dust suppressants, other than water, on unpaved roads.** These regulations will help reduce SPM levels that are currently at unhealthy levels.
2. **We recommend the use of polymers and/or asphalt emulsions to suppress dust on unpaved roads.** These two agents are the most readily available, cost effective, and environmentally safe agents at present.
3. **We suggest more experimental testing of five feasible agents for Thailand.** Polymers, asphalt emulsions, magnesium chloride, calcium chloride, and distillery waste can be used in Thailand in the near future. Specific data to compare the variables of each agent would be best determined by experiments involving actual applications to unpaved roads.
4. **We advise the researching of lignin as a potential dust-suppressing agent for Thailand.** Although lignin is used extensively in the United States and Canada for dust suppression, we were not able to collect any information regarding its potential for use in Thailand.
5. **We recommend the use of magnesium chloride for unpaved roads in Thailand once it becomes available from the potash project in 2003.** A large supply of this by-product that can be used to suppress dust will enhance its cost effectiveness.

6. **We suggest that further environmental impact studies be undertaken to gain specific data pertaining to the use of dust suppressants on unpaved roads.** The agents should be further analyzed to more accurately ensure no harmful effects exist from applying them to an unpaved road.

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Appendix A – Questions Developed for Interviews

Governmental Regulations Interview:

What are the current regulations for suppressing dust on temporary unpaved construction site roads?

What led to the development of these regulations?

Are there any specific studies or statistics that provided data on which to base these regulations?

How are the regulations being enforced?

Are more aggressive regulations being looked into?

If so, by what standards are these regulations being set and what levels are being aimed for?

Is there anything else you feel that is important to the issue of dust control on unpaved roads that you would like to mention?

Potential Producer Interviews:
Note: Questions were slightly adjusted for each interview.

What products does your company presently produce and what are they used for?

Is your company involved in other activities aside from the production of polymers?

What are the base materials for your product?

Do you know specifically what chemical composition your product will come in? If so, what is it?

How are those chemicals suited for dust suppression?

What concentration will your product be offered in?

Are you aware of any possible odors that might be associated with your product?

Are you aware of any possible environmental effects that your product may have?

Are there any health effects that may be caused from handling or coming into contact with your product?

Where will the production site be?

What form will your product be offered in, either solid, emulsion or solution?

What research has been done to prove the effectiveness of your product?

Do you know how long your product will last, in specific environmental conditions, before reapplication is needed?

Will you be transporting and applying your product for your customers or only selling it to them?

How will your product be transported from place of production to site of application?

How will your product be applied to an unpaved road?

Do you have an idea of the potential costs of your product?

How long will it take your product to become commercially available?

How easy will it be to get governmental approval for use of your product?

Are there other details about the production, application, or effectiveness of your product that you would like to add?

Contractor Interview

Unpaved Roadway Maintenance:

Is there a budget for unpaved roadway maintenance?

What are the costs of employing a maintenance crew?

What are the costs of the equipment that is used by an unpaved roadway maintenance crew? How many kilometers of unpaved roadway do these numbers represent?

How much does it cost to purchase aggregates and fines that are necessary for the repair of unpaved roads?

How often is routine maintenance performed?

Are there any other factors or costs that should be considered in the unpaved roadway maintenance process?

Dust Suppression:

Is there a budget for dust suppression on unpaved roads? If so, how much is it?

On average, how long do the unpaved roads exist?

How much are the labor costs for the employment of a dust suppression crew?

What equipment is being used?

What are the costs of the equipment being used in terms of operation and maintenance?

How many kilometers of road can a water spraying crew treat in the course of day?

Where does the water come from, i.e. is it taken from the drinking water supply or from other sources?

What is the cost of obtaining the water?

Are there a set number of applications done in a day? If so, how many? If not, what method is used to decide the frequency of application?

In determining the use of a chemical dust suppressant for Thailand to use on unpaved roads, in what order of importance would you place the following attributes?

- effectiveness
- cost
- environmental impact
- odor

Are there any other factors that concern you about the suppression of dust that should be included?

Ministry of Industry Interview:

General Questions:

What role does the Ministry of Industry play in government affairs?

What exactly is the process by which the magnesium chloride is produced as a waste product?

Is the potash project something that is already being done, something that is being set up, or something that is only being looked into at present?

Where exactly is the site of production?

What is done at present or what is planned to be done with the magnesium chloride waste from this process?

What are the costs associated with disposing of the waste?

Governmental Issues:

Do you think that the government will impose restrictions upon the use of this waste as a dust suppressant? If so, how easy do you think it will be to get permission?

What government regulations are involved in the disposal of this waste?

Availability:

What form is the magnesium chloride in when it is considered to be waste? Is it a solid or in solution?

If it is in solution, do you know what % of a solution the magnesium chloride is in?

Does it have other uses that you are aware of?

What is the exact composition of this waste?

How much of this waste is or will be available in terms of volume or mass?

Will it be available free of cost? If not, what will the cost be?

What is the projected daily production of this waste how much magnesium chloride can we expect to be extracted?

Environmental Issues:

Are there any harmful environmental effects that you are aware of concerning the disposal of this waste?

We are aware of the presence of magnesium chloride, but what else does it contain that we need to worry about if we are to apply it to a road?

Appendix B - Roundtable Handout

Controlling Dust On Unpaved Roads In Thailand

February 23, 1999

A project in conjunction with:

Chulalongkorn University
Bangkok, Thailand
and
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Worcester, MA, U.S.A

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Worcester Polytechnic Institute

Problem Statement:

The problem of suspended particulate matter in Thailand has been well documented by a series of studies. These studies have concluded that efforts need to be made to reduce the amount of particulate matter in the air for the sake of public health. Although much of the PM-10 in the air comes from automobile exhausts, a significant portion can originate from unpaved roadways. In the urban areas the unpaved roads are predominantly located at construction sites and are temporary. In more rural areas the unpaved roads exist between villages. In either case there are demonstrable benefits to reducing the dust from those roads. At present Thailand uses, if anything, water to control dust. The problem with water, although it is cheap, is that it requires frequent re-application to be effective. Our project focussed on looking at other more effective methods of suppressing dust and how viable these were for use in Thailand.

Goal Statement:

The goal of our project is to determine suitable dust suppression agents for use in Thailand. Suitability is determined by:

- Dust suppression ability
- Cost effectiveness
- Environmental Impact
- Feasibility of use in Thailand

Methods:

To obtain the required information for this evaluation, we performed an extensive literature search to learn about the possible agents. We also interviewed many people in Thailand to determine the feasibility of using dust control agents. During these interviews we would discuss such things as environmental impacts in Thailand, as well as any governmental regulations that may be encountered upon implementation. All of these things are important, as they will be reflected in the final recommendations that we provide.

Today we will give you a complete overview of our findings and provide recommendations for suppressing dust in Thailand. We have taken into consideration the weather conditions in Thailand, including the three seasons. Based on prices and availability recorded from our interviews we performed a cost analysis study for each feasible agent to find the approximate cost to apply the agent in Thailand. We will also suggest solutions for temporarily unpaved roads as well as more permanently unpaved roads in the rural areas. We believe that these recommendations will help Thailand with their dust problems in an environmentally and economically sound way.

Analysis of Dust Suppressants:

From our literature review, we found many possibilities that have been used in various locations in the World for suppressing dust. Here we overview the various agents that have been used and the particular properties that enable them to work as dust suppressants.

The agents that have been used as dust suppressants are divided into three categories:

- Salts
- Emulsions
- Industrial waste products

Salts:

There are two types of salt that are used for dust suppression. The first agent is calcium chloride and the second is magnesium chloride

Calcium Chloride:

- Used throughout United States
- Applied in a 38% solution with a spray truck
- Hygroscopic: attracts water and that way weighs dust down
- Penetrates deep into the surface of the road
- Not currently produced in Thailand; imported from Israel for 10-13 Baht/kg to Bangkok
- Potential to produce in Thailand if demand is great enough
- Effectiveness decreased during the wet season
- Potentially harmful effects from leaching and runoff to plant and animal life as well as drinking water
- Corrosive to metal objects
- Application rate is 2.5 Liters/m^2

Magnesium Chloride:

- Used throughout United States
- Applied in a 32% solution with a spray truck
- Hygroscopic
- Deep penetration into the road
- Not currently commercially produced in Thailand; imported from Israel for 12-15 Baht/kg to Bangkok
- Waste product of salt production in the Mahasarakham region. This waste is simply thrown away and could be obtained for free
- Potential for production if demand is great enough.
- Not effective during the wet season
- Potentially harmful effects from leaching and runoff to plant and animal life as well as drinking water
- Corrosive to steel

Emulsions:

We found two types of emulsions that have been used widely as dust suppressants. The first type is the polyvinyl acrylic emulsions and the second is the asphalt derivative emulsions

Polyvinyl Acrylic Emulsions:

- Used throughout United States
- The correct type of polymer is currently produced in Thailand, but not used as a dust suppressant
- Production takes place in Chon Buri and the price is 40 Baht/kg
- Dilution 1:4 by volume with water
- Added solvent is texanol
- Application rate is 0.3 Liters/m^2
- Re-application is every 2 months

- Price will definitely fall if a large demand arises
- Polymers coat the road surface retaining water and binding dust particles together
- Minimal penetration into the road surface causes easy wear away of coating
- Polymers are non-leaching and have no harmful effects on the environment because they are applied topically
- The only effects arise if polymers are directly applied to vegetation
- Texanol evaporates immediately into the air and is considered non-polluting

Asphalt Derivative Emulsions:

- Special kind of asphalt derivative readily available in Thailand from any petroleum company
- Price is 10 Baht/Liter
- Application rate is 1.13 Liters/m^2
- Reapplication is twice a year
- This asphalt contains no oil making it environmentally safe
- Asphalt derivative dries to a hard resin
- Asphalt derivatives cover road surface and retain water in the road preventing dust becoming airborne

By Products:

The following agents are by-products of industrial or agricultural processes. Four potential agents were found: sugar beet extract, distillery waste, soy bean oil and lignin sulfonate.

Sugar Beet Extract:

- Hygroscopic due to potassium chloride
- Not grown in Thailand, only cooler climates
- Closest alternative is sugar cane, but sugar cane factories use all of the wastes

Distillery Waste:

- By-product of distilleries
- Readily available from distilleries throughout Thailand
- Used as fertilizer by farmers close to the distillery
- Waste product, free other than transportation and application costs
- Classified as industrial waste, needs special government approval for use on roads in Thailand
- High BOD levels
- Environmentally harmful to open bodies of water
- Cannot be used during rainy season
- Acid property means corrosive to passing cars
- Associated odor, smells like coffee
- Each distillery produces 500-600m^3
- Application rate is 30 m^3/km (road 6 m wide)
- Reapplication needed approximately every 15 days
- Makes roads slippery

Lignin Sulfonate:

- Used throughout southern and western U.S., as well as Canada
- Waste product of paper mills
- Sticks loose particles together to form a tightly packed road surface
- Environmentally safe
- Biodegradable
- Corrosive
- Unfavorable odor
- Creates a slippery surface

Soy Bean Oil:

- Used in the Midwestern U.S.
- Soybean feedstock processing by-product
- Binds soil particles together
- Penetrates 3 cm
- Applied 1.3 l/m^2.
- Heating to 57 °F provides easier application and better results
- Minimal curing time

	Material Cost (Baht/m^2)	Available	Environmental Harm	Application
Calcium Chloride	15.00	Yes	Potential	Easy
Magnesium Chloride	14.61/free*	Yes	Potential	Easy
Polymers	2.81	Yes	None	Easy
Distillery Waste	Free	Yes	Unknown	Easy
Asphalt Emulsions	1.88	Yes	None	Separate Truck
Soy Bean By-product	N/A	No info	None	Heated
Lignin	N/A	No info.	None	Difficult
Sugar Beet/Cane Extract	N/A	No	None	N/A
Water	Free	Yes	None	Easy

* Waste product of salt farming in Mahasarakham

Preliminary Conclusions:

From the information we have gathered, it is feasible for Thailand to use dust suppression agents on unpaved roads in the near future. At this point, the most viable options appear to be magnesium and calcium chloride, polymers, and distillery waste. Although distillery waste is classified as an industrial waste, it can be readily available for inexpensive use as a dust suppressant if allowed by the proper governmental agency. Sugar beet/cane by-products are not a good option in Thailand. Asphalt emulsions may be a good option for the future, but there is not enough data currently available for us to thoroughly analyze it. Similarly to distillery waste, the fact that lignin is a by-product, and hence a waste product, means that it could be available at a low cost from Thailand's paper mills.

Further Analysis:

The above considerations immediately rule out some of the options for use in Thailand. After these there are still four alternatives available that need further consideration to provide recommendations. These four alternatives are calcium and magnesium chloride, distillery waste, and polyvinyl acrylic emulsions. These options may be better suited for some areas of Thailand than others. Their local suitability would depend on proximity to resources and regional weather conditions.

It is important to take into consideration the location of an unpaved road when deciding upon the most suitable agent to use. The polymer producer is located in Chon-Buri, which makes it a cost-effective option to use on roads located in that general area or those areas that are near a port. However, for roads in northern Thailand, the first option may be to determine how close a distillery plant is located to the road. This type of consideration is also necessary for the two types of salts. They are delivered to Bangkok and need distributing from there to the site of application. Magnesium chloride is a useful option in the northeast because it is a waste product of salt farming and could be obtained for free. The distance from the source to the site of application is important as the suppression abilities of the agents differ. Due to this transport costs become an important factor in determining cost effectiveness.

In terms of the climatic conditions of Thailand, it might not be practical to use a different dust suppression agent in the rainy season. The most cost-effective means of suppression may be for the contractors to make decisions on a daily basis. When a road surface is particularly dusty, they can decide to spray water down for a temporary solution, as a longer means is not required due to the frequency of rain. Another reason why other agents may not be suitable for use in the rainy season is due to monsoons. The monsoons can greatly reduce the durability of suppression agents, as well as create a large amount of runoff.

	Effectiveness In Rainy Season	Best Usable Location	Effectiveness
Magnesium Chloride	Poor	Central/South/ North East	Best
Calcium Chloride	Poor	Central/South	Very Good
Polymers	Good	Central/South	Good
Distillery Waste	Poor	Near distillery	Not Known

Cost Benefit Analysis:

As part of our project, we are performing a cost-benefit analysis. The cost benefit analysis is looking into the costs of applying these various agents and comparing them to the economic benefits to reducing the amount of dust in the air. Air pollution forces many people to seek medical treatment every day. This not only costs the individual, but also the government, who greatly subsidizes the health care system. By reducing the amount of dust in the air, fewer people will need to see a doctor and they then represent savings to the government. We believe this analysis may show that the savings in health care subsidies due to reduced particulate matter levels are greater than the costs of suppression. As the agents differ in application costs and effectiveness, we have developed a model that takes both of these into account and provides us with a method of comparison. This model will also allow us to make projections into the future where clearly prices and health costs are going to change. This is work in progress that will be discussed and analyzed at the presentation.