Dust Control On Unpaved Roads
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This project was funded by the Minnesota Local Road Research Board (LRRB). Legislation creating the Board was passed in 1959. The board appointments are made by the Commissioner of the Minnesota Department of Transportation (Mn/DOT). It includes four county and two city engineers whose terms are set at a maximum of two 3-year positions. Persons serving from Mn/DOT include the Director of the Research Administration Office, the State Aid Engineer, and the Research Administration Engineer, who also serves as secretary. A representative from the University of Minnesota serves as the tenth member.

Monies for LRRB projects come from municipal and county state aid funds (up to 1/4 of one percent). This money is put into a research account and is used for:

- Conducting research for improving the design, construction, maintenance and environmental compatibility of state aid highways.

- Constructing research elements and reconstructing or replacing research elements that fail.

- Conducting a program for the monitoring and implementation of research results.

The program is approved on a calendar year basis by the LRRB Board.
This report summarizes dust control procedures on unpaved roads used by various states and local agencies. The research results related to dust control are also outlined. The report starts with a brief introduction on dust problems associated with unpaved roads and three main dust control methods: chemical, mechanical, and administrative. Preliminary concepts and background of a temporary surface treatment for dust control are presented. The relative effectiveness of a dust control program is estimated based on traffic levels, road conditions and the climate. The report discusses various materials used in dust control, selection of a proper dust palliative, dust control procedures, and evaluation of a dust control program. Results from a survey sent to Minnesota city and county agencies are presented summarizing current dust control practices used on unpaved roads. The report concludes with evaluation and recommendations based on the survey results and an extensive literature review.

(29 references, 17 figures)
Dust Control On Unpaved Roads

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The opinions, findings and conclusions expressed in this publication are those of the authors and not necessarily those of the Minnesota Local Road Research Board or the Minnesota Department of Transportation.
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DUST CONTROL PROCEDURES ON UNPAVED ROADS
Review and Evaluation

1. Introduction

Nearly 50 percent of America's roads are unpaved (unsurfaced, graded in situ for ADT typically less than 50 or granular surfaced for ADT typically between 50 and 400). Additionally, an even larger percentage of private roads and parking lots are unpaved. An increasing problem associated with these unpaved surfaces is dust generated by vehicles and wind. In addition to environmental and health hazards, dust can cause mechanical problems in cars, higher maintenance costs for buildings, and a higher risk of automobile accidents due to dust clouds. Hoover (1973) [10] showed that the concentration of silt-sized particles in the air behind a car moving at 35 mph on a moderately dusty unpaved road was about 100 times the pollution concentration in the air of an industrial city. More importantly, dust can carry several hundred feet, penetrating nearby homes and covering crops. Crop growth is stunted due to the shading effect and clogged plant pores. In human health, dust is a common cause of allergies and hay fever, and may be a conveyor of diseases.

In addition to the environmental concerns, a long term maintenance consideration is the loss of fines associated with dust, which causes higher maintenance costs in grading, blading, graveling and patching. For example, in the typical Iowa climate, for every vehicle traveling over one mile of unpaved road, once a day, every day of the year, one ton of dust is deposited along a 1000-ft-wide corridor centered on the road; i.e., quantity of dust equals 1 ton/mile/year/vehicle at ADT=1 and 100 tons/mile/year/vehicle at ADT=100 [10]. This produces a tremendous loss of fines on road surfaces. Furthermore, the coarser material will be thrown or washed away from the road surface which causes the road to begin to ravel, rut, and washboard. Consequently, deterioration accelerates until costly repairs are needed.

There are three major methods to control dust:

1. A chemical method, is to construct an unpaved road with a dust suppressing/binding agent. This includes surface treatments from oil to magnesium chloride. The primary objective of these materials is to cause the finer particles to be bound firmly with the other constituents of the road material. For instance, a hygroscopic chemical agent pulls moisture from the atmosphere into the gravel surface; as a result, the fines can be kept in place and compacted, thereby holding the surface together better.

2. A mechanical method, is the use of geotextiles and surface materials in road construction and reconstruction. Instead of a reactive approach, this method takes into account dust control in designing the gravel road geometric structure. If surface material itself has the capability of physical stabilization, it can be used alone for dust-free surfacing.

3. An administrative method, is to enforce the speed limit. Speed reduction at certain levels can tremendously reduce the pulverization of road material and dust emissions. The third method was discussed in detail by Metzger (1967) [15]. It was shown in their study that dust emissions were reduced by 40 percent if the average vehicle speed was reduced from 40 mph to 35 mph.

As early as the 1920s the United States' Highway Research Board reported on dust control programs [22]. Since then, a major improvement has been achieved. After a successful surface treatment, dust content is tremendously reduced in the range of 30 to 80 percent and aggregate pullout is reduced in the range of 25 to 75 percent, respectively, within a short distance of dusty roads.
In this report, dust control is considered a temporary solution, i.e., an intermediate treatment between watering and paving. Although some of the materials (tars and bitumens) can be used in more permanent surface treatment operations such as seal coats, they can also be used as dust control agents. In other words, these materials are treated as dust control agents only if they are used as a temporary surface treatment.

The second section of this report describes the traffic volume criteria and lists factors and conditions that limit the effectiveness of dust control. Dust control agents are discussed in Section 3, where a comprehensive review of the existing agents is presented. The fourth section describes the procedure for selecting a proper agent, based on a rating process. In Section 5, specifications are reviewed and discussed. Section 6 presents an evaluation procedure including the considerations of cost-effectiveness. Finally, in Section 7, the results of a survey throughout Minnesota cities and counties are statistically presented.
2. Preliminaries

This section gives normal traffic volume criteria and factors influencing decision making of temporary surface treatments on unpaved roads to control dust and retard the formation of corrugations. According to the Transportation Research Board [22], an average daily traffic (ADT) of 500 is a common acceptable cutoff for cost-effectiveness of dust control agents with the exception of poor subgrade, although the cutoff criterion may vary considerably depending on policy and specific site requirements. If the subgrade is poor, the cutoff of 500 ADT should be reduced. Roads with less than 15 ADT generally do not require dust control. Traffic volumes above 500 ADT generally require multiple treatments and consideration of more expensive and more permanent surface treatment.

This document will not attempt to establish a definitive volume at which any particular treatment should be used. Usages vary by local conditions and conventions among states or countries. Furthermore, economic considerations often override the normal traffic volume criteria for the use of surface treatments. Maintenance philosophies may also dictate the level of traffic at which a temporary or permanent surface treatment is applied. In view of other installation decision factors, dust control using chemical/mechanical methods can be justified when:

- paving is not feasible because of lack of funds or limited use of the road;
- the cost of the dust control materials and application is low;
- stage construction of the road is planned.

A general indication of the expected effectiveness of dust control procedures is given based on the following factors: traffic conditions, climate conditions, surface conditions, and environmental concerns. A dust control program is not beneficial if any of the following conditions exist:

- the road structure is not properly constructed and maintained;
- the road is not capable of servicing the expected traffic;
- subgrade drainage is inadequate and surface drainage is improper.

A dust control program may be beneficial but not cost-effective if any of the following conditions exist:

- the traffic volume (ADT) is more than 500;
- the climate is rainy;
- the subgrade is granular containing higher amount of fines;
- fine content (% minus No.200 sieve) of surface material is less than 5 percent or more than 30 percent.
3. Materials

Many different surface treatment materials, under a variety of brand names, have been used for dust control over the years. These materials are called dust control agents and can be formed either in liquid or in solid forms. An acceptable dust control agent should satisfy the following basic requirements:

- be environmentally compatible;
- be easily applied with common road maintenance equipment;
- be workable and respond to maintenance;
- provide reasonable retention and control of dust;
- provide little loss of riding quality;
- be cost competitive.

3.1 Inorganic Chemicals

Inorganic chemicals have a usage estimated at 75 to 80 percent of all dust control agents. All dust control agents in this category are salt type or deliquescent compounds and work the same way. After being spread or sprayed onto an unpaved surface by a road crew, they dampen and penetrate due to a hygroscopic reaction which pulls moisture from the atmosphere into the aggregate surface, causing the road fines to stay in place and holding aggregate particles together. The popularity of inorganic chemicals can be attributed to their environmental compatibility. A study on dust control agents prepared for the Environmental Ontario Waste Management Branch of the municipal government of Toronto found no adverse effects on water or plants from the use of calcium chloride as a dust control agent. The effect of salt on ground water is minimal because it migrates vertically in soil and stays in place in dust control and road stabilization work. A recent study by Golden (1992) [29] indicates that the use of magnesium chloride dust control product poses little environmental risk.

The performance of these agents depends on such conditions as: temperature, relative humidity, and traffic. Each of these conditions affects the agents differently. Some agents are not effective at certain temperatures and humidities, while others are only partially effective. In the following, main inorganic chemical dust agents such as calcium chloride, magnesium chloride and sodium chloride will be discussed in detail.

3.1.1 Calcium Chloride

Calcium chloride has been used to treat unpaved road surfaces since the last century. It retards evaporation from the road during the daytime heat. However, because it starts to absorb water from air at 29 percent relative humidity (77°F), calcium chloride recaptures lost moisture at night or during other favorable humidity conditions. Figure 1 shows the lowest value of the relative humidity and the corresponding temperature at which calcium chloride will absorb moisture and completely dissolve (Brudal, 1941) [22]. In this figure, in

![Figure 1. Relation between the lowest relative humidity and temperature at which Calcium Chloride will absorb moisture and dissolve (Brudal, 1941).](image-url)
areas where the temperature and humidity are in the zone to the right of the curve, calcium chloride will
absorb sufficient moisture for it to dissolve. Therefore, under these conditions, calcium chloride is of great
value as a dust control agent. As a result of this process, surface tension of water film between particles is
significantly increased helping to slow evaporation and further tighten compacted soil. This adds strength to
the treated surface. Additionally calcium chloride lowers the freezing point of the water solution to -60F,
iminizing the possibility of frost heave since the freezing process is gradual and seldom completed.

In summary, calcium chloride keeps the unpaved surface damp, binds the aggregate parts together, and keeps
the fines in place. As a result, unpaved surfaces become compacted over time (the chemical slowly
penetrates the surface, several inches, and stabilizes material). In addition, a treated road can be regraded
and recompacted with less concern of losing moisture or density. Calcium chloride is relatively effective over
a wide range of temperatures, humidities and traffics.

Conversely, calcium chloride does have some disadvantages compared to other dust control agents. Calcium
chloride has a limited time period of effectiveness, usually 6 to 12 months. During application, the principal
disadvantages of calcium chloride are its corrosive action to vehicles and its slipperiness in extremely wet
conditions (its ability to attract moisture prolongs the active period of corrosion). This corrosive effect
increases the equipment maintenance cost and causes damage to vehicles. For the effective control of dust
with calcium chloride, the road surface must be well-graded, stable mixes. Additionally, calcium chloride is
highly soluble and easily leached out by rainwater unless the road has a proper crown for rainwater to be
deflected sideways into ditches. During dry periods, upward capillary action may cause chlorides to
crystallize near road surface, where they can be leached away by sudden rain. During the application of
calcium chloride in its dry form, it is mixed in water, and this process releases heat as it dissolves which
could be a safety hazard. In view of this environmental concern, care in handling is required because spills
of concentration may kill or burn vegetation.

3.1.2 Magnesium Chloride

Magnesium chloride has the same effect as calcium chloride does with the exception that at a temperature
above 77F and relative humidities below 32 percent, magnesium chloride starts to lose its moisture attraction
and retention capabilities. This exception limits its effective application range. Compared with calcium
chloride, magnesium chloride is more effective for increasing surface tension, which results in a very hard
road surface. Therefore, magnesium chloride is widely used in the northwestern part of the U.S.A.,
particularly for stabilizing the surfaces of haul roads. Instead of lowering the freezing point to -60F as
calcium chloride does, magnesium chloride lowers the freezing point to -27F. A comprehensive comparison
between calcium chloride and magnesium chloride was made by Reyier (1972) [17]. If dust control is the
only concern, Reyier’s results indicate that 18 percent more magnesium chloride (than calcium chloride) is
needed in order to achieve an equal control level for equal lengths of time.

3.1.3 Sodium Chloride

Sodium chloride has the same effects as calcium chloride and magnesium chloride with a few exceptions. At
76 percent relative humidity and above 77F, sodium chloride starts to absorb water from air. This property
reduces its effective application range. Of all salt type dust control agents, sodium chloride is the least
expensive. When mixed into road base, sodium chloride effectively improves mechanical stability. Also, it
lowers the freezing point of a water solution to -6F. However, as sodium chloride becomes diluted or leaches
out, it disperses clay which shrinks during the drying process becoming susceptible to wind erosion. Most
importantly, if over applied, sodium chloride poses a threat to plants and animal life as well as groundwater
contamination. It slightly reduces the rate of evaporation and increases surface tension slightly less than
calcium chloride.
However, unpaved surfaces coated with natural and processed sodium chloride do not hold up well. Treated surfaces are not effective at holding ambient moisture; therefore, dust is easily raised. These surfaces become rutted, and loose gravel builds up along the sides of the road. Thus, sodium chloride typically is used to stabilize the road base and is topped with calcium chloride to control dust.

3.1.4 Sodium Chloride and Calcium Chloride Mix

While controlling dust effectively, a mix of common salt and calcium chloride cuts the material cost considerably. Compared to calcium chloride used alone, the mixture of calcium chloride and sodium chloride reduces the cost by 20 percent while losing less than 5 percent in dust control because it combines the stabilizing action of sodium chloride with the dust control action of calcium chloride.

3.1.5 Sodium and Potassium Silicates

Sodium or potassium silicates will precipitate insoluble aluminum and calcium silicates, which act as binding agents. Their use is limited since they are expensive and not often available in large quantities. Another disadvantage is that an additional (second) application is required because the sodium silicates and aluminum salt have to be applied separately.

3.1.6 Surfactants

Surfactants (soap-like substances) are generally ineffective as dust control agents because of their high evaporation rate.

3.1.7 Water

Water poses no threat to the environment. However, unless it is raining, it evaporates quickly making it an ineffective dust control agent. Generally, it suppresses dust for less than a day; therefore, water provides only temporary relief, and the required frequency of application strongly depends on the weather. In order to achieve the same level of dust control, repeated application is necessary causing water to cost more than other inorganic chemical suppressants due to the intensive labor/equipment costs.

3.2 Organic Chemicals

Organic chemicals have a usage estimated at 15 to 20 percent of all dust control agents. These products are adhesive and waterproofing, and generally form coherent surface layers that seal the road surface and physically hold or bind the soil particles together. Because of waterproofing, they act as a soil stabilizer; however, their cost is usually prohibitive unless the treatment precedes some type of paving. Typical agents are bunker oil, asphalt prime coats, asphalt emulsions, lignin sulfonate and vegetable oils.

3.2.1 Petroleum Oils, Emulsions and Bitumens

Petroleum oils and emulsion are derived from crude oils. They offer soil binding because of the adhesive properties of asphalt. The most favorable effect is their flexibility for a wide range of soils, gravel, and traffic conditions. Also, they provide a water repellent road. Under dry conditions, some oils may not stay resilient resulting in a breakup under load and eventually potholes. In addition, these products are substances that can stick to objects moving on the surface, and are frequently tracked into buildings along with dirt. Another disadvantage of using these materials is that they can choke roadside foliage. Furthermore, the cost of these materials is significantly higher with respect to other chemical suppressants such as calcium chloride. Waste oils may contain heavy metals such as zinc, lead, etc. The amount of heavy metals may cause
environmental concerns. In particular, the use of waste oil is limited by regulations for handling and disposing of hazardous substances. For example, the Minnesota Pollution Control Agency (MPCA) has outlawed the disposing and placing of "used oil" on the ground.

The most successfully applied palliative in this category is Coherex, manufactured by Witco Corp. and locally distributed by Hawkins Chemical, Inc. It is a stable, concentrated, nonvolatile emulsion consisting of 60 percent semi-liquid natural petroleum resins and 40 percent wetting solution. It is diluted with water at the ratio of 1 to 4 or 1 to 7 for different expectations of effectiveness. Compared with other palliatives, Coherex is the most effective and its control efficiency reaches 90 percent (Harley, Hunts, and Cass, 1989) [8]. Because Coherex solves dust problems for a wide range of soil types and climates, it has become popular throughout the nation. In particular, Coherex is most cost-effective for spot applications.

In order to cut down the cost of bitumens used for both dust control and grading, a new ultra-light (low viscosity) bitumen has been developed in Queensland, Australia (1986) [28]. It has been shown to be a good alternative to grading unsealed roads several times a year. This new and cheaper ultra-light cutback bitumen is expected to stay intact for three to four years and provide a good seal on the road. The ultra-light surfacing will cut down on dust and is expected to prove no more costly than grading the roads several times a year.

3.2.2 Lignin Sulfonate

Lignin sulfonate is a waste product of the sulfite pulping process in the paper industry. Like oils, lignin sulfonate, and its derivatives, are natural cements that bind dust particles aided by associated sugars which act as hygroscopic agents. Lignin sulfonate greatly increases the dry strength of soil. During wet periods, Lignin sulfonate is also an excellent dispersing agent for clays. As the clay swells, Lignin sulfonate aids in plugging pores, resulting in reduced water penetration. It is interesting that with the addition of a calcium carbonate slurry the corrosive effects of Lignin sulfonate are counteracted. This reduces their solubility, thereby prolonging dust control capacity. Material cost for Lignin sulfonate is comparable to that of inorganic chemicals. Where aggregate binding is concerned, ammonium-base sulfides are superior to sugar-free calcium-base sulfides.

Lignin Sulfonate and its derivatives offer minimal or no stabilization benefits. Because of its solubility of solids content in water, the surface binding action of Lignin sulfonate may be reduced or completely destroyed by heavy rain. These materials become slippery when wet and brittle when dry. Additionally, they may cause corrosion of aluminum and its alloys. Special requirements on the wearing surface include that it be a well-graded soil-aggregate mix, the surface be loosened to a depth of 1 to 2 inches just prior to initial application, and fine content be in the range of 4 to 8 percent. Local availability usually limits its usage.

3.2.3 Vegetable Oil

These agents, which include linseed and cotton-seed oils, wool grease derivatives, soybean oil, and soapstock, are oil by-products of processing and are usually available only in small quantities. These agents can be adapted to suit a wide range of soils. No special equipment is needed for applying them. However, since they will only coat individual grains of soil and they have little binding power, their effectiveness of controlling dust is not particularly satisfactory. These agents have a tendency to be very liable to oxidation and to form a brittle surface. When in the form of tar, these agents are more effective; however, the availability in that form is limited.
3.3 Road Fabric

A new concept for dust control (geotextiles such as road fabric) was introduced by Blackwood and Drehmel (1979) [3]. Instead of direct suppression, the geometric structure of unpaved roads is modified either in the construction or reconstruction stage. Road fabric is flexible, durable, water permeable, and highly resistant to soil chemicals. Such a stable material can be used as a separator to prevent the intermixing of the subgrade and base course materials, thereby preserving the drainage systems and load transfer capacity. As a result, the structural life is prolonged and maintenance costs are reduced. As discussed above, fabrics do not add any strength to a road layer system, but instead, improve the overall function of the system. Preliminary studies by Blackwood (1979) [3] indicate that fine material will pass through the fabric without blending and that fines in the fine-grained subgrade soils will not pump up into the aggregate, thereby serving to control dust production. In tension, fabrics reduce the localized loads over a larger area of the subgrade, thereby improving the support properties of the system and avoiding structural failure induced by dust. In new construction, fabric might reduce the amount of aggregate required in the design of unpaved structure sections and then, reduce amount of fine particles in the aggregate. On the other hand, special surface materials containing enough fines are needed. Although material cost is high, installation cost is low. Material degradation of the fabric may result from exposure to ultraviolet rays (sunlight).

In Gilford, New Hampshire, three kinds of surface material were placed over a non-woven geotextile, Supac 4NP, to a depth of 4 in., and were tested (Heine, 1991) [9]. The surface materials used were Bluestone, Ledgepack, and a 1.5-in. crushed bank run aggregate. Bluestone is a regional name for an angular, granular material, crushed ledge mixed with many fines. Compared with Bluestone, Ledgepack is a little more angular and has fewer fines. The 1.5-in. grade, crushed bank run is a common gravel in New England with fines and angular stones. To date, Ledgepack seems to maintain the best surface performance and acts well with a minimum amount of dust. The geotextile is performing well with all of the surface materials, with respect to its ability of helping to reduce the loss of the road surface.

3.4 Dust-free Surface Materials

A proper surface material alone can result in a stable, low cost, low volume road that generates a minimum amount of dust. In Redwood county, Minnesota, milled materials recycled from a cold milling process were used for dust-free aggregate surfacing. If the temperature is high enough, the application of milled materials for unpaved roads is feasible. The combination of the dust control program with the pavement material recycling program provides cost-effectiveness.

In Apache county, Arizona, limestone fines and pit run aggregates were successfully used to aid dust control, add smoothness, and decrease maintenance (Broadbent, 1988) [4]. From a stockpile of reject fines in a limestone mine (in which most of the material was smaller than 0.5 in.) a 4-in. layer of the limestone fines was placed on an experimental one-mile section where the ADT was 120. This section has performed very well for the past six years. The road has required only occasional blading to maintain the roadway in good condition. Compaction without watering is a key in this whole process. Even though local availability limits its application, an underlying concept is that limestone fines are compounds of calcium and result in some cementation and then a good performance.

3.5 Hybrid Agents

Various hybrid products are emerging (e.g., a bitumen-lignin dust control agent), which pose opportunities for cooperative test projects.

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4. Selection

Selection of dust control agents, the determination of the application rate and frequency of selected agents are mainly based on the cost-effectiveness of the agents. Assuming that a low volume road was properly constructed, the selection, application rate, and frequency of a dust control agent depends on the cost, properties of the agent, the mixture properties, environmental requirements, traffic volume, soil type, surface material properties and weather extremes.

4.1 Basic Selection

Local conditions, state environmental regulations, material and equipment availability, and the road users' viewpoint play an important role in the basic selection of dust control agents. Besides the local conditions, other factors influencing a selection are environmental impact, traffic volume, subgrade type, climate and surface material properties. These factors can be considered in a rating system to make a preliminary selection. The system should be based on the existing literature related to the effectiveness of dust elimination.

4.1.1 Environmental Concerns

Environmental impact is the first important factor in selecting an agent. The main concern is the release of harmful elements which are contained in a chemical agent. Chemical analyses of agent solutions are used to determine the content of the chemical constituents. The environmentally unacceptable constituents (e.g. heavy metals) and their concentration can be identified. If applied onto a road surface, they may leach into the ecosystem depending on the leaching resistance of the soil and the chemical mix, particularly on road surfaces near lakes and farm sites. A direct way to evaluate the contamination of harmful constituents to adjacent property and their background values is to conduct water quality sampling of the surrounding area. A water quality sample may be taken from standing water in ditch bottoms. Final results should be compared to state regulations.

4.1.2 Traffic Considerations

In the range of traffic volume discussed in Part 2 (less than 500 ADT), the life expectancy of dust control agents decreases with increasing traffic volumes. This is particularly true for lignosulfonates and most petroleum products, which create a hard surface crust subject to breaking, thereby causing potholes. Therefore, for higher traffic volume, dust control agents with a strong penetrating and stabilizing effect are more effective.

4.1.3 Climate Concerns

Because of the sensitivity of chemicals to the climate, local conditions should be evaluated before selecting a chemical agent for dust control. For example, some hygroscopic chemical agents will lose their hygroscopicity as relative humidity decreases. Some agents may not maintain their resilience under dry conditions. In particular, chlorides and lignosulfonates tend to leach out and wash away under heavy rain; also, they may become slippery when wet. Mixes with petroleum products also may tend to be slippery in wet weather. Lignosulfonates tend to work better in dry climates due to their cementing action which binds the particles together without relying on atmospheric water, and the fact that they are soluble in water.

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4.1.4 Subgrade Type

Soil classification is needed to identify the type of subgrade material (clay, sand, silt, etc.). Sometimes, subgrade soils may mix with the surface materials and have an impact on the quantity of fines. As a result, the effectiveness of dust control is influenced by the type of subgrade material with respect to the properties of the surface material and of the dust control agents.

4.1.5 Properties of Surface Material

Whenever possible, the dust control agent should be selected to work with the existing surface material. For this purpose, surface materials have to be quantified. A sieve analysis is needed to determine the fine content (percent passing 75 μm (No.200) sieve), which is the most important factor in dust control. Material passing a 75 μm sieve size is defined as the fines portion and may be referred to as minus No.200 sieve size (0.0075 mm, 71 μm, or 80 μm sieve size).

To determine the moisture content of surface material, the laboratory calibrated "Speedy" moisture meter or the nuclear moisture-density gauge (Hoover et al, 1981) [12] can be used. Soil density may be obtained to determine the rate and amount of penetration. However, if surfaces have been loosened by scarification, most agents will penetrate and coat most soils. In the case where no compatible agent can be found for a particular face material, it may be necessary to modify the surface material by adding fines or gravel to improve the gradation.

4.1.6 Rating System

A good selection can be achieved using a rating system established by a comprehensive review of existing literature [26]. Table 1 provides a selection chart of dust control agents with respect to environmental impact, traffic volume, subgrade type, and surface material (fine content and moisture content). In this table, the rating of a palliative with respect to effectiveness is rated as 2 for good, 1 for fair, and 0 for poor. The summation of the rating numbers from each of the five categories indicates an estimated effectiveness of the given dust control agent for the specified condition. The higher the value, the more effective the agent will be. If an agent has more than one zero, two points should be deducted from the summation, the resultant sum is a reasonable estimator of dust control effectiveness.

Table 1. Selection chart based on ratings

<table>
<thead>
<tr>
<th>Traffic Volume (ADT)</th>
<th>Subgrade (Type)</th>
<th>Climate</th>
<th>Surface Material</th>
</tr>
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<tbody>
<tr>
<td>&lt;100</td>
<td></td>
<td>Rainy</td>
<td>Fines content</td>
</tr>
<tr>
<td>100-250</td>
<td></td>
<td>Normal</td>
<td>(% passing 75 μm sieve)</td>
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<tr>
<td>&gt;250</td>
<td></td>
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<th>Silt</th>
<th>Sand</th>
<th>&lt;40% RH</th>
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<th>5-10</th>
<th>10-20</th>
<th>20-30</th>
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<td>MgCl₂</td>
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<td>2</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>0</td>
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<td>1</td>
</tr>
<tr>
<td>Ligno-sulfonate</td>
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<td>0</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>2</td>
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<tr>
<td>Petroleum agents</td>
<td>1</td>
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<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
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</table>
4.2 Selection of Alternatives

In Section 4.1, a basic selection of general type of agent is discussed. Very often, for the type selected, alternatives may exist. To obtain the maximum benefits, selection among alternatives is very important and depends on the properties and the cost of the agents.

4.2.1 Properties of Dust Control Agent

Langdon and Williamson (1985) [14] summarized required properties of agents for dust control and corresponding methods to evaluate these properties.

Penetration
Evaluation of penetration is not applicable to dust control agents which do not penetrate into unpaved roads, such as asphalt emulsions. To evaluate penetration, both rate and depth of penetration should be considered. The penetration rate is a measure of curing time and penetration depth; this rate indicates the effectiveness the agent has with respect to soil stabilization.

As suggested by Langdon and Williamson (1985) [14], penetration may be evaluated with the help of the cone penetration test. The agent to be evaluated is poured into the conical depression in a soil block. The depth of the depression and the time for the agent to penetrate into the block are then recorded. A satisfactory penetration requires a rate of 0.00039 in/sec.

Evaporation
In the evaluation of evaporation, three major concerns are the rate of evaporation, concentration of solution, and constituents of distillates. As soon as an agent is applied, the process of evaporation begins. Water or diluent acting as a carrier evaporates and leaves a residue that controls dust. The rate of evaporation affects the depth of penetration and effective period of treatment. The rate of evaporation is determined by exposing a known amount of agent to the local climate and measuring the weight loss over time.

Water (Leaching) Resistance
Water solubility or water dispersibility during application and water insolubility after application are important factors in selecting a proper dust control agent. Good water resistance of agents after application prevents leaching of binders and provides long term chemical binding. In view of environmental concerns, a higher resistance to leaching reduces the small amount of toxic constituents in the chemical agents from leaching into the ecosystem. The possibility of leaching is determined by placing and agitating a residue-soil mixture in a test tube of distilled water and by noticing any change of coloration or conductivity [14].

Cohesion or Abrasion Resistance
The ability of an agent to improve the strength of road surfaces (i.e. binding effect) provides some immunities to deterioration by traffic abrasion and weather conditions. This may be accomplished by either apparent cohesion due to capillarity or by actual cohesion due to the residue binding effect. Not only the binding effect, but also the rebinding effect is important for holding surface material undergoing repetitive traffic loads. Therefore, the surface, bound by a proper agent, is expected to remain flexible. For instance, the newly formed fines bound by an agent with medium viscosity has good flexibility. The abrasion resistance of an agent may be determined by the modified pellet abrasion (MPA) test, in which a soil-residue pellet, placed in a jar mill, is abraded for a given residue content [14].
Aging Resistance
Aging resistance of an agent indicates its lasting effect and resistance to environmental conditions. For example, oil becomes hard and brittle because of its relatively low aging resistance. Aging resistance may be evaluated with the aged-pellet-abrasion test over time. In fact, this test is similar to the abrasion resistance test with the exception that the time effect is included.

4.2.2 Cost of Dust Control Agents
Table 2 lists the sources and cost for each of above mentioned products, which are available locally in Minnesota. Only material cost is considered herein for the purpose of selection; the cost related to transportation, application and preparation is discussed in Section 6.1, where a complete dust control program is evaluated. All products are listed on a cost per gallon for brine solution and a cost per pound for flake or pellet. Also, based on past successful experience reported, the application rate and frequency are listed.

Table 2 Road dust control agents

<table>
<thead>
<tr>
<th>Agent Name</th>
<th>Price</th>
<th>Application rate</th>
<th>Frequency</th>
<th>Source</th>
<th>Phone No.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Flake (¢/lb)</td>
<td>Pellet (¢/lb)</td>
<td>Liquid (¢/gal)</td>
<td>Flake (lb/yd²)</td>
<td>Pellet (lb/yd²)</td>
</tr>
<tr>
<td>CaCl₂</td>
<td>12.5</td>
<td>16.5</td>
<td>75.0</td>
<td>1.0-1.5</td>
<td>0.8-1.3</td>
</tr>
<tr>
<td>MgCl₂</td>
<td>-</td>
<td>-</td>
<td>75.0</td>
<td>-</td>
<td>0.4-0.5</td>
</tr>
<tr>
<td>NaCl₂</td>
<td>-</td>
<td>1.8</td>
<td>-</td>
<td>2.0-5.0</td>
<td>-</td>
</tr>
<tr>
<td>MC30</td>
<td>-</td>
<td>60.0</td>
<td>-</td>
<td>0.1-0.4</td>
<td>1</td>
</tr>
<tr>
<td>SOAP STOCK</td>
<td>-</td>
<td>107.0</td>
<td>-</td>
<td>0.3-0.5</td>
<td>1</td>
</tr>
<tr>
<td>COHEREX</td>
<td>-</td>
<td>97.0</td>
<td>-</td>
<td>0.2-0.3</td>
<td>1</td>
</tr>
<tr>
<td>SUPAC</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

4.3 Determination of Application Rate and Frequency
The proper selection of a dust control agent can reduce the application rate and frequency. However, the complexity of a real case makes the ideal choice impossible. By adjusting the rate and frequency, the cost-effectiveness can still be accomplished. The application rate and frequency vary depending upon:

- type of agents
- degree of dust control required
- condition of subgrade
- type of wearing surface
- traffic volumes
- type of vehicles and speeds
- climate considerations
- frequency of maintenance
Generally, a higher rate or greater frequency is required when:
- traffic volumes with high speeds and a high percentage of truck traffic are present
- the relative humidity (e.g., calcium chloride) is low
- fine content in the surface gravel is less than 10 percent
- wearing surface is loose and poorly bladed.

4.3.1 Application Rate

Application rate is best determined by trial and error and from successful past experiences (Table 2). If a simple testing apparatus, such as a uniaxial compression apparatus, is available, the application rate can be rationally determined with a testing program. Hoover et al. (1973) [11] introduced the triaxial mix screening testing program to evaluate such an ability with respect to the compressive strength of treated materials (c.f. Hoover et al., 1981) [12]. Standard triaxial tests were conducted on 2-in. high by 2-in. diameter cylindrical specimens. The specimen was a mixture of surface materials and dust control agents with various mixing ratio. Unconfined compressive strength was determined for each mix. The specimen was molded in the laboratory and the application rate giving the maximum compressive strength could be determined by varying the mixing ratio.

Different testing programs could be used to determine the application rate. Langdon and Williamson (1985) [14] used the method of relying on abrasion resistance of a mix from the MPA test instead of the compressive strength of the mix. In the MPA test, the content of an agent in the mix needed to provide adequate cohesion was estimated. For petroleum products, laboratory tests conducted by Langdon indicate that the concentration of the agent in the mix at a 20 percent weight loss in the MPA test was found to be a good measure for an adequate cohesion. To achieve this concentration, different application rates with respect to different petroleum products can be determined. As an example, if the weight loss of a mix in the MPA test reaches 20 percent, its corresponding content of the residue could be used to determine the application rate. As shown in Fig. 2, the application rate is plotted against the residue content of the mix at 20 percent loss in the MPA test for different concentration percentage of solution. With the help of this figure, a proper application rate can be determined from known product concentration and mix concentration.

It is easy to determine the application rate using the trial-and-error technique in a small scale, especially when the application rate suggested by the manufacturer or other experienced engineers fails to provide effective control of dust for a special road surface.
4.3.2 Application Frequency

Frequency of application is best determined by successful past experience (Table 2). However, a rational approach (Langdon and Williamson, 1984) [14], could be referred to. If the effective life of the treated surface in terms of vehicles is defined by using an evaluation procedure, it is linearly related to an application rate for a given kinematic viscosity as follows:

\[ N = a + bn - \log \mu \]

where:
- \( a, b \) = constants depending on subgrade type, properties of surface material and climate;
- \( N \) - the effective life (number of vehicles);
- \( n \) - the application rate (gal/yd\(^2\));
- \( \mu \) - the kinematic viscosity of the residue (cSt).

With the comparison of the design (expected) life traffic and the actual traffic, the frequency of application can be determined.
5. Procedures

Dust control agents alone cannot make a bad road good. First, for all but resinous adhesive agents, the road surface to be treated should contain sufficient moisture to achieve uniform distribution of the dust control agent. If natural moisture is lacking, the road must be prewetted with water to assist the chemicals in penetrating the surface uniformly. Secondly, adequate drainage and shaping is important for agents to be effective. Ditches and culverts should be reshaped, cleaned, or replaced where necessary. Shoulders should be bladed down so water can not be trapped. If aggregate materials are needed for shaping, an aggregate gradation mix with enough moisture should be used to ensure design density compaction. When needed, fine materials available nearby can be incorporated into the road mixture. Thirdly, weather condition should be accounted for. For example, chemical and organic agents should be applied under neither frozen nor rainy conditions nor below a temperature of 40F. Tar and bitumen agents should not be applied in either foggy or rainy conditions and below temperatures 50F to 60F. Finally, usually more than one treatment a year, with the second being diluted, is generally necessary. These specifications for applying agents on unpaved roads are according to reports from the US Army Corp of Engineers [1], MN/DOT [27], and USDA Forest Service [25].

5.1 Procedure with Liquid (Non-solid) Agents

The procedure discussed in this section is applicable for the application of agents with good penetration. Equipment required for applying a liquid agent includes a motor grader to blade the area to be treated and a water truck or other liquid carrying transport unit with distribution equipment to prewet and/or apply brine solution dust palliative. A pneumatic roller and a steel-wheeled roller may be required to compact the bladed surface. With a satisfactory road surface, the dust control procedure with brine solutions can be achieved in the following steps (Armstrong, 1987) [1]:

1. Blade away all ruts, potholes, washboards and loose excess surface materials to expose a hard surface and shape the road surface to a straight line slope of 0.5 to 12 in. type-A crown to permit the water to run off the road and eliminate pounding. If normal traffic is unable to provide adequate compaction, compaction of the bladed and shaped surface with a rubber-tired roller is suggested.

2. Prewet new surface with water at rates ranging from 0.03 to 0.3 gal/yd² to reduce surface tension, to allow maximum penetration of the agent, and to ensure uniform application. With the known in-situ moisture content of surface material, the optimum water content can be obtained by adjusting the application rate of the prewetting water.

3. Apply a solution of agents to the road surface at the rate determined immediately following prewetting. Agitation during transport and application helps to prevent segregation of the solution. Close attention should be given to the location of the spray bar (or spray hose) to ensure that a 6 to 12 in. overlap is maintained on successive passes. Whenever a discontinuity (i.e., fisheyes) occurs due to poor driving of distributor, application should be terminated and additional water should be applied for resuming the process.

4. Allow treated area to cure until vehicle passage can be achieved without treated material sticking to wheels. Curing takes between 0 and 4 hr depending on the soil type and the climate. Finer grained materials may require a longer curing time. If necessary, compact the treated area after curing is completed.

5. A second treatment is recommended prior to the first treatment becoming totally ineffective. For the best results, the second treatment should take place in late summer or early fall if the first was in the
The application rate for the second treatment should be 50 percent of the initial concentration. The road surfaces may be relabeled if necessary. Following periods of low humidity, the hygroscopic properties of inorganic chemicals is rendered ineffective or dormant and can be reactivated with an application of water at 0.1 to 0.2 gal/yd². Periodic watering should continue for the duration of dry periods. If the area to be treated is in relatively good condition (no ruts, washboarding, or potholes), then prewetting, application of the dust palliative, and compaction from normal traffic are all that is necessary.

5.2 Procedure with Solid Agents

Equipment for the application of solid agents includes a motor grader, a water truck, and a truck spreader or powered spreading machine. The following are the main steps in this procedure:

1. Follow steps 1 and 2 described in Section 5.1.
2. Spread the agent uniformly at the rate determined. Make adequate moisture available by adding water to the road surfaces. Allow the treated surface to cure sufficiently enough to prevent excessive pickup under traffic.
3. Follow step 5 in Section 5.1.

5.3 Procedure for Mixed in Place Agents

If an agent does not have an adequate penetration, mixing-in-place is required. The required equipment for this procedure is a motor grader, a water truck, a pulverizer, a sheepsfoot roller and a rubber-tired roller. The main steps are listed as follows:

1. Water and shape the road surface with the upper 1 to 2 in loosened to allow for blade mixing, follow steps 1 and 2 of Section 5.1.
2. Mix thoroughly scarified materials using the pulverizer, several passes of which are required to achieve a desired break up of aggregates to sizes less than 1.0 to 1.5 in. Remix scarified materials after watering, obtaining the optimum moisture content.
3. Apply dust palliative uniformly by longitudinal blade mixing, coupled with rotary mixing using pulverizer add water as necessary to achieve the optimum moisture content.
4. Blade the mixture into a windrow along one edge of the road, then spread the windrow in two equal lifts. Each lift should be compacted with a sheepsfoot roller until the tamping feet "walk out". Blade the mixture finally for crown and compact it with a rubber-tired roller for a final furnishing.
5. Allow the mix to cure long enough to prevent excessive pickup from traffic.

The above procedure is also suitable for base stabilization.

5.4 Other Procedures

Some simple cost-saving procedures for dust control have been reported. For example, treating only a center strip of the roadway on less traveled roads and spot-treating on a cost-share basis with roadside residents.
6. Evaluation

A requirement for evaluating a dust control procedure is to have a way to measure the benefits and performance. A standard assessment procedure was developed for road agencies. This procedure attempts to take into account the numerous variables that may affect the results of a dust control program, such as road condition, climatic conditions, traffic conditions, application procedure, maintenance procedure, performance assessment and monitoring, and cost benefit assessment.

6.1 Performance evaluation

Performance evaluation of a dust control procedure is based on the measurement of the amount of dust given off by a treated road at any given time. Three main measurements are listed.

6.1.1 Dust condition rating

Visual investigation and evaluation is known as a dust condition rating. This rating method relates to visibility and has a scale of either 0 to 5 percent or 0 to 100 percent. The scales are based on a minimum visibility (maximum dust) of zero. The conditions of treated and untreated surface are visually monitored in the field with respect to time. Besides the dust condition rating, the condition of the road surfaces, degree of dusting behind traffic, riding quality, rutting, potholes, and surface cracking should be included in the overall evaluation. The scale of 0 to 5 percent appears more suitable since it is difficult to distinguish among percent degrees of dust conditions, as defined by the 0 to 100 percent scale.

6.1.2 Photographs

Photographs of the dust generated by a passing test vehicle provide a permanent record for the visual evaluation of the treated road.

6.1.3 Dust collectors

A dust bucket collecting procedure is provided in ASTM D1739-70 for collection and analysis of dustfall. However, some other procedures similar to ASTM's have been used. For example, Handy et al. (1975) [6] and Hoover et al. (1981) [12] used collectors consisting of a 6-in. diameter by 7-in. high semi-rigid plastic container, clamped to the upper portion of a steel support stake 4 ft. long. The collectors were installed at 10 ft. to 450 ft. intervals parallel to the road centerline, beginning at the top of the foreslopes. The closer to the road centerline collectors are, the denser they are installed. Each collector was positioned about 3 ft. above ground surface and half-filled with distilled water. Because of evaporation each collector was examined to maintain the water level at half height once a week. Collection periods ranged from three to four weeks. Considering circumstances, such as collectors can be destroyed by farm animals or equipment, more than one series of collectors are suggested. After collection, each bucket was sealed and transported to the laboratory. In low temperature ovens, excess water was evaporated and then seeds, chaff, insects, and other organic contaminants were removed from the contents. The samples were then treated with 0.3N H$_2$O$_2$ acidified with HCl to further remove organic matter. Finally, the samples were dried at 110°C and then analyzed.

In the studies by Handy et al. (1975) [6] and Sultan (1976) [21], quantity of dust particulate collected was calculated as kilogram per hectare per month (1 lb/acre/day equals to 33.6 kg/hectare/month). Fig. 3 shows the dust distribution from the tested road (see also Smith, 1942 [18], Becker, 1978 [2], Hoover et al., 1973 [11], Hoover et al., 1981 [12]), with distance on a semi-logarithmic scale. By linear regression, two straight lines usually intersect near the secondary road right-of-way (ROW). Therefore, road dust was considered in two categories, roadside and distributed. In addition, the average atmospheric dust deposition in the study
was indicated in this figure according to Smith et al. (1970) [19]. When more data on dust distribution became available, a logarithmic function was suggested by Hoover et al. (1981) [12] with dust being quantified by pounds/acre/day/100 of ADT. Furthermore, the quantity of dust was correlated to particulate level, expressed in terms of concentration of particulate per volume of air (μm/m³). The comparison to allowable particulate adopted by air quality regulatory agencies could then easily be made. It was found that dust at the ROW was about three times the assumed ambient dust level.

The fixed dust bucket collectors discussed above provide an overall dust condition in the dust disturbed area. If only dust on the road is concerned, the collectors can be attached to a passing vehicle. In this case, quantity of dust is calculated as dust weight per length. However, air flow may interfere with dust collection.

Based on the comparison of dust measurements during pre and post-applications (on treated and untreated surfaces), the effectiveness of dust control agents could be evaluated. Analytically, the superposition of the distribution curves obtained before and after a dust control agent has been applied onto the road will indicate the extent of dust reduction.

6.1.4 Effectiveness of Dust Elimination

The three evaluation indices discussed above can be combined into a single index, the percentage of dust elimination. The percentage of dust elimination is a function of time which starts at the first application of the dust palliative. As shown in Fig.4, the dust elimination level decreases with time. For a given application, such a curve may also help in determining the frequency of application.

6.2 Cost-effectiveness Evaluation

Besides dust control effectiveness, cost-effectiveness is another appraisal of a successful program.

6.2.1 Program Costs

As suggested by Hoover (1973) [10], the criterion for considering the potential of dust control program is $.35/yd² or less in 1973 with $.70/yd² as absolute maximum. Generally, quantity of agents must not exceed 4 to 5 percent by dry soil weight. The overall cost of a dust control procedure can be divided into four categories:

*Road Upgrading*

If a poor area is selected for treatment, upgrading is essential to obtaining maximum benefit from a dust control program. Therefore, the cost of upgrading should be included as part of the overall cost. Conversely, in many cases, road improvements would be required regardless of whether a dust palliative is used or not. In these cases, upgrading cost should not be included in the program. Items included in
upgrading cost are: drainage improvements, geometric improvements, repairing failed areas, and adding surface materials.

**Surface Preparation**
This includes manpower and equipment costs directly attributable to preparing the surface before and immediately after the application of dust agents. These costs include: manpower, equipment selected materials (fines or coarse materials) to meet dust agent requirements, scarifying, watering, shaping, compacting, traffic control and detour costs.

**Product Supply**
Two major costs in this category are material cost and transportation cost. Material cost has been discussed in Section 4.2.2; transportation cost is limited to local shipment cost (generally, material cost reflects shipment cost from the manufacturer to a local representative).

**Application**
Application costs are manpower and equipment costs for applying the dust palliative on road surfaces. Quite often suppliers will quote a supply and application lump sum cost, especially suppliers that can deliver the dust palliative in a distributor truck. In some cases, the suppliers will also send a product technician to supervise the application, thereby lessening the agency’s manpower costs. These items should be clarified at bidding.

### 6.2.2 Benefits

The overall benefits are both tangible and intangible. The tangible benefits are the direct benefits of applying a dust palliative on an unpaved road, particularly in a long term. Due to the binding effect of the dust palliative, the loss of fines is reduced. Except for spot applications, a successful dust control program will provide tangible savings from a maintenance perspective. The intangible benefits are from the elimination of dust.

**Tangible Benefits**
The tangible benefits result in a direct cost saving to the agency involved. These include reduced grading costs, reduced frequency of blading, reduced regravelling cost, and reduced patching cost. All of these reduced maintenance costs may result from the binding effect of dust palliatives. For example, as a direct result of CaCl₂ application, Winona county in Minnesota was able to go to a 7-ton Spring Restriction on CaCl₂ roads with minimal adverse effects. Actual dollar values are best obtained by keeping local records before and after a dust palliative has been used. From existing literature it has been found that a 25 to 75 percent cost reduction in blading and regravelling can be expected by using a dust control program. Percentage of cost reduction depends on dust control agent type, surface condition, maintenance degree and cost calculation procedures.
Intangible benefits
The intangible benefits represent a benefit to other segments of society. They include reduced vehicle
damage, reduced accidents, higher quality of life and property values, reduced cleaning cost, reduced dust
related health problems, reduced sedimentation in water bodies, reduced impact on dust sensitive vegetation,
and reduced complaints from public. These intangible benefits result from the elimination of dust on the
roads by using dust palliatives. It is clear that the elimination of dust increases safety and results in
invaluable benefits. In many instances, these benefits will singly promote the use of a dust control program
and the tangible benefits are an added bonus.
7. Dust Control in Minnesota

With the development of the gravel surfaced roads and the concern of dust problems to nearby residences, more and more cities and counties in Minnesota are implementing a dust control program (at least spot applications). Although major improvements have been made, there is still a need to control dust effectively or low cost improved roads.

7.1 Minnesota city and county survey

To determine local traffic, road and climate conditions, a survey was conducted throughout Minnesota cities and counties during the summer of 1991. The survey asked what dust control agents were locally available, what treatments were being used, which treatments have been effective, and what are the costs and potential savings from reduced maintenance. Out of a total of 111 cities and 87 counties, 90 questionnaires (36 cities and 54 counties) were returned representing 46 percent of all Minnesota agencies. This section summarizes results of the survey.

7.1.1 General

Based on 90 responses, Fig.5 shows the distribution of agencies with different percentage of gravel roads. As shown, 42 agencies, most of which are cities, have gravel on 10 percent or less of their roads. 48 agencies, most of which are counties, have a percentage of gravel roads greater than 10 percent. Percentages of responding agencies having dust control experience and programs are shown in Fig.6a and Fig.6b, respectively. Results of the survey with respect to the material used for dust control are presented in Fig.7.

Figure 5. Distribution of agencies with different percentages of gravel roads.

Figure 6. Dust control in Minnesota: (a) experience; (b) program.
7.1.2 Local Conditions

Survey results of local conditions including traffic, subgrade type, fines and moisture condition of the surface material are summarized in Fig. 8.

Figure 7. Dust palliatives used in Minnesota.

Figure 8. Local conditions in Minnesota.

Figure 9. Equipment used in Minnesota: (a) solid agent; (b) liquid agent.
7.1.3 Procedures

Survey results of the equipment (Fig.9a and b), numbers of a crew (Fig.10), specification followed (Fig.11), application rate (Fig.12) and frequency (Fig.13) are presented.

7.1.4 Costs

Survey results of costs, corresponding effectiveness and duration of dust elimination, and savings from reduced maintenance are presented in Figures 14 through 17, respectively. Because most of the agencies either have a small percentage of gravel roads or only use spot applications, the number of the agencies which had benefits from a dust control program is relative low (7 of 35). However, these agencies do have a well-established dust control program and, in general, treat their gravel roads to suppress dust on a regular basis. Therefore, they obtained tangible benefits in maintenance savings from their dust control program (with 50% reduced blading cost and 25-50% reduced regravelling cost).
7.1.5 Summary

Most agencies in Minnesota are using a spot application of dust palliatives in front of homes and near farm sites. Therefore, the effectiveness of dust elimination is the main objective for these agencies. Additionally, most agencies are using calcium chloride (CaCl₂) as a dust palliative probably due to their experiences with CaCl₂ as a deicer. Most agencies are satisfied with the effectiveness of the dust palliative they are using. However, a few agencies failed to reduce dust effectively because of the following:

1. traffic: heavy traffic with higher percentage of heavy trucks;
2. road structure: poor base or sand subgrade;
3. climate: heavy rains or extremely dry for a salt-type palliative;
4. preparation: improper blading or blending too much;
5. application: relatively low application rate or frequency;
6. maintenance: no rewetting for dry condition;

![Figure 14. Cost for conducting a program.](image14)

![Figure 13. Frequency of applications.](image13)

![Figure 15. Effectiveness eliminating dust.](image15)
8. Evaluation and Recommendations

Most of the responding agencies started dust control experiences in spot application and were satisfied with the results. Some agencies are suppressing road dust throughout their system (frequently and long term) and are obtaining benefits from reduced maintenance. However, awareness of an effective dust palliative is limited among agencies. For example, Coherex, an effective dust control agent especially for spot application, is hardly known or used in Minnesota. Compared with CaC\(_2\), Coherex can be applied in a wider range of subgrade soils and dry conditions. Costs, reported by agencies, are in the range between low and medium.

For CaC\(_2\), to control dust more effectively and durably, prewetting before application and follow-up treatment at half of the initial dosage are recommended. Necessary maintenance, (i.e., watering after application) is needed for a long lasting effectiveness, particularly within dry conditions.

If paving is expected on an unpaved road in the future, the combination of soil stabilization and dust control programs is recommended. In this case, the mix-in-place procedure will improve the penetration property of dust palliative. For the use of calcium chloride, Scarifying, wetting, and mixing are major concerns in the procedure. The amount of calcium chloride to be applied is suggested to be about 0.5 lb/yd\(^2\) per inch of depth. The treated roads in such a way may provide excellent subgrades for higher-class pavement or even excellent base courses for certain types of pavements, besides the elimination of dust.

A dust control program can also be incorporated with the maintenance programs of unpaved roads. After the blading in the routine of a regular maintenance program, the calcium chloride is recommended to be applied at a rate of 0.75-1 lb/yd\(^2\). When the calcium chloride has been completely absorbed, the treated surface needs drag-blading.
Acknowledgement

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