ROAD DUST MANAGEMENT: STATE OF THE PRACTICE

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This paper provides a background for the 1st Road Dust Management Conference, to be held on November 13 and 14, 2008, in San Antonio, Texas. It will be presented in the opening session to provide a platform for the following presentations, thereby eliminating the need for presenters to provide basic background information at the beginning of each presentation.

1. INTRODUCTION

There are millions of miles of unsealed roads around the world, which are managed by the national road authorities, state or provincial road agencies, local authorities, the forestry and mining industries, agriculture, national park authorities, and tourism, railroad, and utility companies. There are also numerous unproclaimed roads that no authority takes responsibility for, but which serve a need such as access to informal communities in developing countries. Unacceptable levels of dust, poor riding quality, and impassability in wet weather are experienced on much of this global unsealed road network, and although it is acknowledged that these roads are fundamental to the economies of almost every country in the world, many of the management practices followed leave much to be desired, with programs for dust control, chemical stabilization, low-cost upgrading, etc, largely overlooked. There are no comprehensive guidelines for implementing dust control programs.

Chemical dust control on unsealed roads has been researched for decades and there are numerous published papers documenting the establishment and monitoring of experiments. However, much of this has been agency-specific and mostly focused on assessing performance of one additive under a particular set of conditions. There are no specific comprehensive guidelines or specifications available to help practitioners with establishing longer-term dust control programs, identifying which type of additive would be most appropriate for a specific application, undertaking life-cycle analyses, quantifying negative environmental impacts and positive social benefits, designing appropriate treatments, applying the additive, and maintaining the treated road. Similar documentation for sealed roads has long been available and is continuously updated. Additionally, there is no national industry group serving the interests of additive manufacturers and suppliers, similar to the National Asphalt Paving Association (NAPA) and the American Concrete Paving Association (ACPA). There is no "owner" for documentation, procedures and test methods relating to chemical dust control, similar to the American Association of State Highway Officials (AASHTO), nor is there a sustained source of national funding for research to prepare this documentation and develop procedures and test methods.

Increasing concerns with regard to deteriorating air quality, the sustainability of repeatedly replacing gravel on unsealed roads, and the increasing costs of asphalt binders used for sealing roads have placed renewed interest on road dust management. Although upgrading the road to a sealed (asphalt surface treatment, asphalt concrete, or portland cement concrete) standard is always preferable and usually the most economic option in terms of life-cycle costs, the rapidly increasing costs associated with this practice results in less distance being upgraded each year. The application of various additives can provide satisfactory dust control on most road surfaces until such time as sufficient funds become available for a more permanent surfacing. Provided that appropriate construction and maintenance practices are followed, and the additives are rejuvenated at regular intervals, chemically treated surfaces are often structurally adequate to function as a base or subbase in a staged construction of a sealed road.

This paper provides a current status of global road dust management together with some points for consideration that may lead to wider implementation of dust control programs in unsealed road management initiatives. The paper includes discussion on the extent of unsealed road networks, the volume of dust generated, the consequences of dust, categorization of road additives, environmental considerations, and dust control research.

2. UNSEALED ROAD NETWORKS

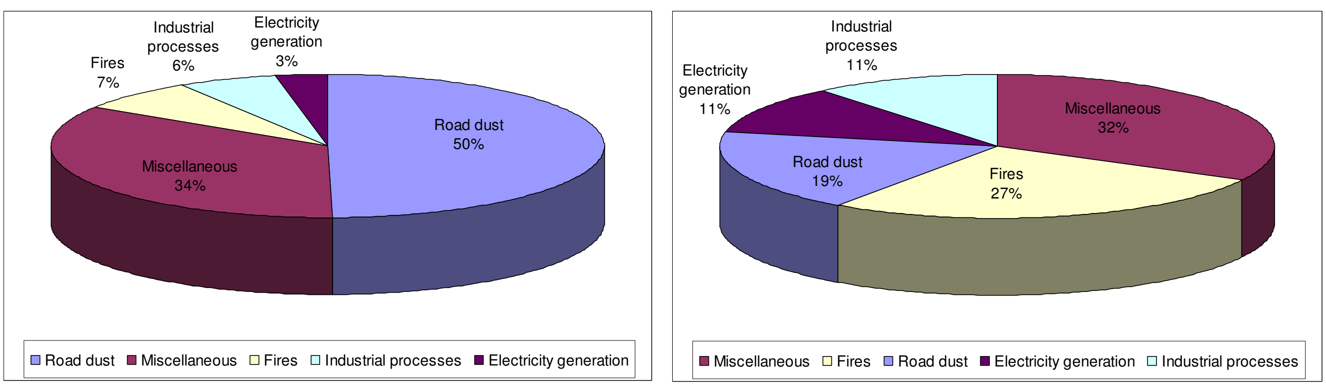
There is no accurate estimate of the size of the global unsealed road network. Table 1 provides some estimates of the extent of unsealed road networks in the United States[1] (1st World, 9,6 million km^2), South Africa[2] (2nd World, 1,2 million km^2), and Tanzania[3] (3rd World, 0.9 million km^2), indicating the magnitude of global unsealed road management issues.

Table 1: Estimates of unsealed road networks (in kilometers)

Owner	United States	South Africa	Tanzania
Land area (km^2)	9,600,000	1,200,000	880,000
Sealed road network (km)	3,700,000	300,000	5,000
Unsealed road network (km)	2,700,000	600,000	85,000
State/county	850,000	150,000	81,000
Municipal	Unknown	200,000	5,000
Forestry	620,000	100,000	Unknown
Bureau of land management	130,000	-	-
Nature conservation/tourism	17,000	5,000	Unknown
Agriculture	Unknown	50,000	Unknown
Mine	Unknown	5,000	Unknown
Other*	Unknown	100,000	Unknown
* Includes service roads for railroad, powerlines, military, border patrol, other commercial activities, etc			

3. VOLUME OF DUST GENERATED

Documented studies in the United States indicate that as much as 50 percent of PM_{10} emissions and 19 percent of $PM_{2.5}$ emissions are attributed to road dust (Figure 1)[3]. Road dust is the single biggest source of PM_{10} emissions and approximately 65 percent of road dust emissions are attributed to unsealed roads. These percentages increase in developing countries that have higher proportions of unsealed roads, and are of particular concern in urban areas with predominantly unsealed infrastructure.



PM_{10} $PM_{2.5}$

Figure 1: US PM_{10} and $PM^{2.5}$ emissions in 2002 by principal source category[3]

4. CONSEQUENCES OF ROAD DUST

Road dust is often considered only as a nuisance or minor safety hazard by many practitioners. However, using models developed by the United States Environmental Protection Agency[5] and calibrated in various countries[6], it can be shown that millions of tons of dust are generated on unsealed road networks every year. Although much of this dust falls back onto the road to be regenerated by the next vehicle, studies have shown that at least a third of it is permanently lost in the form of deposits away from the road (Figure 2), with losses increasing under crosswind conditions.

Figure 2: Fines lost from unsealed roads

Apart from the obvious consequences of reduced quality of life and increased safety hazard for road users, pedestrians, and workers, the loss of fines (which perform an integral material-binding function) from the road surface results firstly in accelerated gravel loss, thereby increasing the frequency at which the gravel has to be replaced, and secondly in more rapid deterioration of the riding quality of the road, thereby requiring more frequent grader maintenance[6]. This has significant economic and environmental implications in terms of regular regravelling programs. Other serious, but often overlooked consequences, include reduced agricultural and forestry yields. These are attributed to retarded plant growth, increased insect activity, crop blemishing, and reduced palatability of pasture and associated reduced yields in terms of dairy production. There are even published reports on accelerated tooth wear of animals grazing in pasture adjacent to unsealed roads[7]. Environmental consequences in terms of air and water pollution and associated health hazards, primarily those linked to respiratory diseases, are also significant, especially in developing countries where a large proportion of urban road infrastructure is often unsealed. Vehicle operating costs increase significantly in dusty conditions, with numerous publications compiled comparing the cost of operating vehicles in dusty and dust-free environments.

5. DUST CONTROL

Dust control can be achieved either by better selection of base and wearing course materials, mechanical stabilisation using two or more different materials to achieve a better particle size distribution and to increase or reduce the plasticity, or by applying a chemical dust palliative. Only chemical treatments are addressed in this paper.

5.1 Chemical Dust Control Categories

Numerous additives are available for dust palliation, improved compaction, and stabilization of unsealed roads. Most of these bind the fine particles together without any significant chemical reaction occurring in the soil, although certain additives will only perform once a chemical reaction has occurred. A number of additives are material and/or climate-dependent and costs vary significantly. It is therefore important that the bonding nature, limitations and life-cycle costs of these additives be investigated and their performance understood before widespread use is considered.

Most unsealed road additives are proprietary formulations, and information regarding their composition is often not readily available. This knowledge gap can limit the extent of applications if no clear information is available with regard to potential human and environmental impacts and in instances where competitive tendering is required. In order to facilitate research, technology transfer, palliative certification, classification of palliative types for different uses, climates and base material types, selection of appropriate additive type and application rate for particular conditions, and transparent and competitive bidding/tendering procedures, additives need to be categorized based primarily on their function and chemistry. A suggested categorization is provided in Table 2[6]. Similar categorizations are used by the US Forest Service[9] and the Environmental Protection Agency. A brief introduction to each category is provided below. Details on the stabilization mechanism and research on laboratory and field testing of each of these categories are discussed elsewhere in the literature.

Most road authorities cannot specify proprietary product names in tender documents. In order to facilitate implementation under these conditions, authorities could consider using category names in tender documentation if a design or experience dictates a specific type of application. Alternatively a performance specification (e.g. dust level reduction) can be used and the contractor can apply an additive of his own choosing, provided that it meets human and environmental safety requirements.

Table 2: Suggested road additive categories

Category	Sub-categories	Examples
Dust palliatives	Water and wetting agents	-
	Hygroscopic salts	Calcium, magnesium or sodium chloride
	Natural polymers	Lignosulfonate, molasses, tannin extracts
	Synthetic polymer emulsions	Acrylates, acrylics, vinyl acetates
	Synthetic oils	Mineral oils, synthetic iso-alkaines
	Petroleum resins	Blend of natural polymer and petroleum products
	Bitumen, asphalt and tar	-
	Other	Industrial wastes
Compaction aids and stabilizers	Synthetic polymer emulsions	Acrylates, acrylics, vinyl acetates
	Synthetic oils	Mineral oils, synthetic iso-alkaines
	Sulfonated oils	-
	Enzymes and biological agents	-
	Bitumen, asphalt and tar	-

5.1.1 Dust Palliatives

Dust palliatives can be applied either as a topical application to a prepared road surface, as a mix-in treatment to an existing road, or mixed into the material during construction or regravelling. Mix-in treatments typically provide significantly improved performance compared to topical applications. Standard engineering considerations such as adequate compaction, road shape and drainage should not be overlooked in the application process. If topical applications are used, it should be remembered that applying additives to roads in poor condition will result in some dust reduction, but will not correct ride-related issues. Depending on the degree of compaction on the surface of the road, topical applications are best applied as a series of light applications over a period of time, rather than in a single application, to ensure adequate penetration of the additive.

- **Water and Wetting Agents:** Water is probably the most commonly used dust suppressant, especially on mines and on industrial sites where it is an effective means of disposing of contaminated water. Surfactants are occasionally added to reduce the surface tension and allow more rapid distribution of the water through the soil. However, in many instances evaporation results in regular applications being necessary to maintain the required level of dust control. This can have a detrimental effect on road performance, including erosion and segregation of fines, which leads to ravelling of the surface material.

- **Hygroscopic Salts:** These additives, which include calcium chloride, sodium chloride and magnesium chloride, absorb moisture from the atmosphere and bind the material particles together, thus preventing them becoming entrained by air associated with moving vehicles.
- **Natural Polymers:** Natural polymers are by-products from a sulfite process commonly used in the pulp and paper industries, from tannin extraction, sugar refining and other plant processing industries. Their composition is variable and depends on the vegetable matter and chemicals used during processing. When used as dust palliatives, they physically bind the particles of the road together, thus preventing them becoming entrained by vehicles. These additives are usually soluble in water.
- **Synthetic Polymer Emulsions:** Synthetic polymer emulsions, or more correctly, polymer dispersions, are suspensions of synthetic polymers in which the monomers are polymerised in a dominantly aqueous medium. Particles are typically 100 nm in size and comprise many individual polymer chains. Numerous formulations have been developed for various soil "conditioning" applications, many of which are potentially suitable for dust control, gravel preservation and strength improvement on unsealed roads. A number of products are currently available, which "glue" the soil particles together to prevent entrainment by vehicles. Strength gains may be achieved, depending on product formulation and application rate and method.
- **Synthetic Oils:** Synthetic oils include base fluids, mineral oils, and unique formulations of synthetic iso-alkaines. They are insoluble in water and are applied to the road surface in undiluted form. Once applied, they agglomerate particles preventing them becoming entrained by air associated with moving vehicles. Synthetic iso-alkaines also provide a chemical bond between aggregates further preventing entrainment and reducing the effects of surface water.
- **Petroleum-Resins:** Petroleum resins are usually a blend of natural polymers and petroleum based additives. They have a similar binding action to natural polymers, but are more resistant to leaching by water.
- **Bitumen, Asphalt and Tar:** Bituminous additives are offered by most petrochemical and asphalt suppliers as part of their product line. Products range in price and durability from simple spray-on applications that will last approximately four weeks before requiring rejuvenation, to thicker applications that can be blinded with sand, which perform similarly to sand seals and which can last up to three years before requiring rejuvenation. Tar-based additives are derived from coal tar or synthetic fuel distillates to which solvents are added to improve penetration. They are used in a similar way to bitumen additives, however, tars, in

general, are known carcinogens and hence their use could have serious health and environmental implications. Their source, composition and potential carcinogenicity should be established prior to considering their use on roads.

- **Other chemicals:** Various chemicals, which cannot be categorised in the list provided above, are introduced to the road industry from time to time. These are usually waste products that are "sticky" and which the suppliers believe will act as effective dust palliatives. Their dust control properties are often "discovered" accidentally during spills or dumping in evaporation ponds and it is these experiences that form the basis for marketing them as road additives. Waste motor and bunker oils, both of which have been used in the past for dust suppression on unsealed roads, are included in this category. Numerous studies have shown significant negative impacts on groundwater and surrounding vegetation, and therefore they should not be used on roads under any circumstances. The Times Beach, Missouri clean up in the 1970's and 1980's, which cost hundreds of millions of dollars to remediate and required demolition and relocation of the entire town, resulted from spraying of dioxin-contaminated oil as a dust control agent on the towns unsealed roads and vacant lots.

5.1.2 Compaction Aids and Stabilizers

Compaction aids and stabilizers are typically applied as a mix-in treatment. Little benefit will be gained by applying these additives as a topical application.

- **Synthetic Polymer Emulsions:** See above
- **Synthetic Oils:** See above
- **Sulfonated Oils:** These additives contain mostly mineral oils, which have been modified with sulfuric acid to form sulfonic acids. Research has shown that the stabilization process is relatively complex and material-dependent. The two properties that potentially make sulfonated oils useful in soil compaction and stabilization are their ability to displace and replace exchange cations in clay and to waterproof clay minerals by displacing the adsorbed water and preventing re-adsorption. Suppliers claim that the additives improve the soaked strength of high plasticity soils and thus their wet-weather passability.
- **Enzymes and Biological Agents:** These additives vary widely depending on their formulation and intended use. In roadway applications, enzymes are mostly used as surfactants to lower the interfacial tension between the surfactant-dosed water and soil particles, thereby increasing capillary penetration into the soil. It is also claimed that some products contain microbes that extract mineral traces from the soil to produce exocellular

polysaccharides, which can act as natural "glues" to bind adjacent soil particles. This could improve the soaked strength of the soil and hence wet-weather passability.

- **Cementitious and Bituminous Stabilizers:** Cementitious (cement and lime), bitumen and tar products have been widely researched. Specifications and guidelines on their use in road material stabilization have been extensively published and are readily available. They are generally unsuitable for unsealed road treatments, but are widely used in improving marginal materials when unsealed roads are upgraded to a sealed standard.

6. ENVIRONMENTAL CONSIDERATIONS

There are significant environmental benefits associated with road dust control, including reduced particulate matter and the preservation of scare natural resources. However, care must be taken to ensure that the use of road additives will not have any significant negative environmental impacts. Potential environmental impacts include plant and animal toxicity, contamination of water resources, and corrosion of infrastructure and vehicles.

No internationally recognized laboratory or field procedures have been specifically developed for assessing the environmental impacts associated with the use of road additives[10]. However, a number of initiatives, mostly voluntary, have been established with a view to assessing potential impacts associated with road dust control (e.g. The Environmental Protection Agency's Environmental Technology Verification program), while a number of state EPA's require some form of product assessment before they can be applied. However, the laboratory procedures are based on those developed for other applications, such as assessing leachates from landfills and although in some instances these are practically appropriate, the lack of a single standard complicates the comparison of additives for a given application. The tests often provide a very worst-case scenario that is often not remotely realistic in road applications, resulting in potentially beneficial additives being excluded from use. A number of field trials have been carried out in the United States and elsewhere to assess runoff characteristics, but the findings are typically dependent on a multitude of factors and hence interpretation of the data and extrapolation of the findings to other regions is difficult. There is also no process for deciding whether the benefits of road dust control outweigh the potential negative impacts associated with an application. The problem is exacerbated for those additives that require periodic rejuvenation resulting in residual product build-up over time.

7. DUST CONTROL RESEARCH

The first reported chemical dust control experiments (i.e. those other than water spraying, which probably dates back to Roman times) occurred in the early 1900's, when chlorides[11] (calcium, magnesium, and sodium) and then lignosulfonates[12] were applied to road surfaces to reduce dust emissions from passing vehicles. No significant new dust control products appear to have been introduced in the period between the 1930s and 1960s, but in the 1970's and 1980's, numerous chemical additives were introduced to the road industry. These included natural and synthetic polymer emulsions, oils and resins, sulfonated oils, enzymes, and various petroleum-based products. Proprietary products, primarily based on these technologies continue to be introduced.

Over the years, varying levels of research have been conducted on the array of dust control and stabilization additives listed above, by additive developers, road owners, and independent researchers. Since the 1920's, thousands of laboratory studies and full-scale field experiments have been undertaken, and numerous publications prepared on the findings. However, implementation in the form of improved road management practices is almost non-existent world-wide, with no clear indication of why road authorities do not consider chemical improvement a standard practice, despite research continually proving the operational, economic and environmental benefits. For example, the conference proceedings of the 1932 Highway Research Board meeting[13] included a paper on the effectiveness of calcium chloride as an unsealed road additive. A literature review of subsequent Highway Research Board and then Transportation Research Board (TRB) publications up to and including the proceedings of the 2006 TRB Low-Volume Roads Conference[14] reveals that calcium chloride experiments continued to be established and monitored, and that papers on their performance continue to be published at regular intervals. However, road authorities appear no closer to wide-scale implementation of calcium chloride (or any other additive) than they did in 1932. This appears to be attributed in part to the establishment of experiments to assess performance under a particular given set of circumstances, as opposed to establishing them to identify boundary conditions of performance and develop guideline documentation and specifications. Despite this observation, valuable data on issues such as comparing performance of topical applications with mix-in treatments[15], stabilization mechanisms[16], and potential environmental impacts[17] have also be collected and documented in many of these studies, which if appropriately analyzed, would contribute significantly to the preparation of appropriate documentation.

Conversely, other strategies for low-volume road construction and management such as soil stabilization with cement, lime, and asphalt emulsions, bituminous surface treatments (sand and chip seals), and full-depth recycling (foamed asphalt, asphalt emulsion, and cement and lime), which were all developed long after basic chemical dust control, are widely implemented. Quality design guides and specifications for these strategies have been prepared at state and national levels in many countries; little or no new experimentation is being conducted, and design engineers consider them in their choice of alternatives as a matter or course. The number of TRB publications on topics such as low-volume road cement stabilization and chip seal design were considerable at the time of the research studies, but have since dwindled to papers on specific project implementation or the development of new test methods and design tools.

7.1 Certification of Additives

A number of initiatives have been taken in various countries in an attempt to overcome this lack of implementation. One such initiative is that of fit-for-purpose certification[8], which entails reviewing the research conducted on a specific additive and the documentation developed from it to determine whether sufficient information is available for an engineer or manager to make an informed decision on its use as a potential alternative in a road design or for maintenance. Certification systems are also used to ensure that additives comply with certain minimum standards, particularly those related to potential environmental impacts. A series of laboratory control tests are usually carried out as part of the review process. The procedure is based on a relative performance evaluation methodology, which:

- Provides potential users as well as manufacturers and suppliers with a measure of the performance of the submitted additive relative to the performance of a range of additives, as well as to the standard specifications of conventional additives.
- Identifies strengths and limitations of the submitted additive, thereby better defining suitable applications
- Facilitates judgement regarding the engineering and economical advantages of using the submitted additive instead of more conventional products

The process typically involves the following:

1. Establishing a technical assessment team
2. Assessing the manufacturers quality management system
3. Assessing environmental compatibility and validity of the material safety data sheet

4. Reviewing research procedures followed and background research that has been conducted
5. Reviewing guideline documentation
6. Control testing
7. Issuing a fit-for-purpose certificate
8. Post-certificate monitoring

Fit-for-purpose certification is ***not*** intended to serve as a formal acceptance or rejection of an additive based on an absolute performance evaluation. It also does ***not*** serve as a guarantee of performance, ***nor*** does it obviate the need to carry out an engineering investigation, including material testing, for every project where the use of the additive is considered.

8. THE WAY FORWARD

There is no clear way forward to ensure that road dust management initiatives will be implemented on a wider scale than current practice. A number of suggestions are offered for consideration. These are mostly institutional reforms and include:

- An "owner" of unsealed road guidelines, specifications, test methods, and management principles needs to be identified and encouraged to take an active role in ensuring that funding dedicated to unsealed roads is used optimally and sustainably. Gravel retention, good riding quality, and safe driving conditions, all of which are enhanced through appropriate dust management programs are key issues to be considered.
- The manufacturers and suppliers of dust palliatives and non-traditional stabilizers should establish an industry body similar to NAPA, ACPA, and other such institutions. This organization could initiate "ownership" as described above, educate road authorities and road owners, introduce procedures for regulating the industry, hold workshops, training course, and seminars, etc.
- A dedicated environmental protocol detailing procedures to be followed for assessing potential environmental impacts of road additives needs to be developed and approved by relevant agencies. This should include appropriate test methods, as well as a procedure for comparing potential benefits against potential impacts. A standard, auditable format for presenting the results will provide road authorities and owners with an appropriate means for deciding on the use of an additive.
- A dedicated research protocol establishing a minimum requirement for research on an additive before it is no longer considered as experimental should be introduced to the

industry and could serve as a basis for fit-for-purpose assessment. This protocol should include procedures for additive description and categorization, literature reviews, laboratory screening, detailed laboratory studies of performance and environmental impacts, full scale field experiments, data analysis and guideline documentation.

- Guidelines and specifications covering road dust management procedures should be prepared in a format that is acceptable and adoptable by county engineers, the US Forest Service, the Bureau of Land Management, the mining industry, etc.
- A module on unsealed road management practices should be written and offered to colleges and universities offering transportation engineering courses.

9. CONCLUSIONS

Road dust control and unsealed road stabilization are significant road management issues. Although considerable experimentation on a variety of chemical additives has been carried out in the last 70 years, very little wide-scale implementation has taken place. There are many reasons for this, including the absence of a national authority, a fragmented industry, and a lack of funding for programs amongst unsealed road authorities and owners.

This conference is aimed at bringing practitioners together to discuss road dust and adjacent area management issues, road dust best management practices, knowledge gaps, research needs, barriers to implementation, and identification of future needs. Participants will attempt to explain why chemical dust control and unsealed road stabilization has not progressed to the point that road authorities can implement wider-scale programs with confidence. Remedies will be sought to initiate the development of nationwide administrative structures, information resources, and consistent experimental and maintenance protocols that, in a manner similar to those already in place for paved/sealed roads, will facilitate the adoption of standards and practices that will improve performance, and reduce both maintenance costs and environmental impacts of unsealed roads. The conference is not intended to be a platform for reporting on another round of experiments, but rather a forum for identifying and overcoming the barriers to wider implementation of the results and recommendations of the past 100 years of research.

A “white paper” documenting the discussion and the recommendations for a way forward will be published after the conference.

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