TOWARDS A SUSTAINABLE MAINTENANCE MANAGEMENT OF RURAL UNPAVED ROADS

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ABSTRACT

Local roads and natural resource access roads represent a large proportion of the Canadian road network. Despite an often limited budget, unpaved road managers must have efficient and safe networks. In this context, the development of a decision support system to manage the maintenance of this type of roads is essential.

Firstly, a major laboratory and field experimental program has been done to determine practical solutions for stabilization and dust suppressant treatment. Secondly, a life cycle analysis for maintenance of rural road networks is performed in order to quantify the environmental impact of these proposed practical solutions. Finally, a multi-criteria analysis that integrates environmental, social, logistical and technical dimensions is developed and incorporated to the decision support system.

The sustainable management of unpaved rural road maintenance as presented in this article is the basis of an innovative way of thinking and managing this type of road networks.

1. CONTENT OF THE STUDY

Local roads and natural resource access roads represent a large proportion of the Canadian road network. Only in Quebec, these roads count for 150 000 of the 170 000 km of all road type, i.e. near 90% of the provincial, municipal and private networks. Because of the low volume traffic and the remoteness of most unpaved roads, the paving of these roads is a hard and expensive task that remains unrealistic. Roads covered with granular materials, called unpaved roads appear to be the best solution. However, with the increasing importance of transportation security, stabilization and dust control of unpaved roads have become necessary. Indeed, dust causes many problems such as reduced visibility, particles inhalation and loss of granular materials causing additional costs. Moreover, due to the severity of northern climate, the challenge is not only to reduce dust but also stabilize unpaved roads in a freezing and thawing context in order to improve road accessibility and quality. It is also important that products used are environmentally friendly. In this context, the development of a decision support system for unpaved roads maintenance managing is necessary and this system should provide practical solutions and could take into account environmental, social, logistical and technical dimensions.

2. RESEARCH PROJECT

Unpaved roads are often used for longer than there expected useful lifetime [1]. These older roads cause significant maintenance costs and require expensive repairs. Often, different users such as forestry companies, vacationers, hunters, fishermen and government employees share the use of unpaved roads. In order to deal with this reality, the maintenance of unpaved road networks is more complex and requires strategic planning based on clear and determined objectives.

Knowing that the stabilization of unpaved roads improves their quality [2], an adequate and strategic maintenance of a road network would help rural road network managers to make profits and improve the quality and the accessibility of their roads.

Several studies have been done in the past few years concerning the treatment of unpaved roads with stabilization agents or dust suppressants [3] [4] [5] [6] [7] [8] [9] [10]. Treatments with dust suppressants and stabilization agents respectively reduce dust and improve the mechanical characteristics of an unpaved road. Some stabilization agents may also act in both ways.

The purpose of the CARRLo (local roads and natural resource access paths) research project [11], which is used to feed the decision support system, was to find adapted and economic solutions for the design, the rehabilitation or the maintenance of performing, durable, safe and smooth unpaved road surfaces. The proposed decision support system for unpaved roads maintenance management will use the results of the CARRLo project as a database.

Studies have shown that there are economic advantages to unpaved road treatment [12] [13]. However, the treatment effectiveness (using stabilization agents or dust suppressants) depends on some parameters like climate, traffic, road location, mineralogy and grading of granular material. Thus, the treatment performance varies widely depending on the context. Very few studies take into account the context of an unpaved road in order to provide an effective treatment for its maintenance. Indeed, most of the studies concerning unpaved road treatment are made for a specific context. The decision support system shown in this paper should help provide practical solutions (stabilization or dust control) for effective maintenance of unpaved rural roads depending on the road context and the network manager objectives and preferences.

3. OBJECTIVE

The objective of the research presented is to develop a decision support system for maintenance of an unpaved road network allowing managers to rehabilitate and maintain their unpaved rural roads depending on their preferences and their specific and determined goals.

4. DECISION SUPPORT SYSTEM DESCRIPTION

The decision support system will be made up of an expert system, an economic filter, a multicriteria analysis and will be followed by a result validation. Figure 1 shows a diagram of the decision support system.

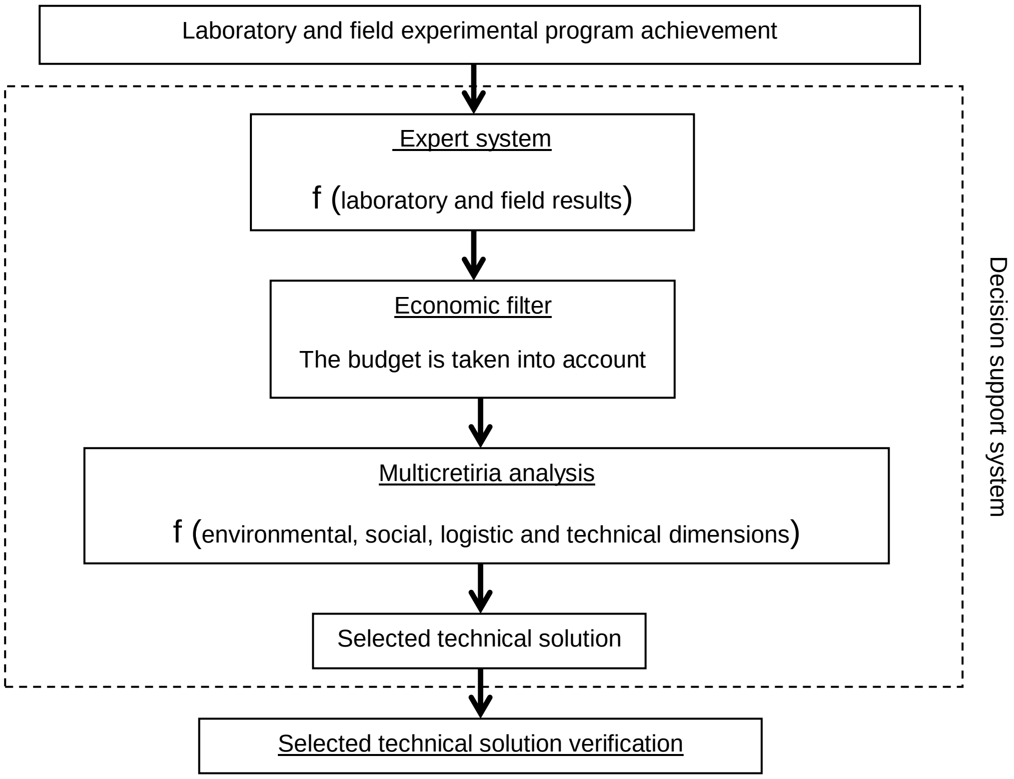

Figure 1 – Decision support system diagram

Firstly, a comprehensive analysis of the laboratory and field experimental program results from the CARRLo project has been done. In particular, the influence of mineralogy and grading on the performance of granular materials stabilized or treated with dust suppressants has been established in order to provide combinations of products and concentrations that promote maximum road quality in a specific context. These experimental variables will be used as inputs of the expert system that will propose a list of solutions for a specific context. A life cycle analysis for the maintenance of rural road network has been performed to quantify the environmental impact of the practical solutions proposed.

Then, this list of practical solutions is subjected to an economic filter. This filter is designed to take into account the budget of the road network manager and ensure that the final solution proposed is economically workable. The purpose of this filter is to eliminate solutions too expensive.

Environmental, social, logistical and technical dimensions are integrated in the multicriteria analysis. This multicriteria analysis will determine the solution for the maintenance of unpaved road network that best meets the needs and preferences of the manager. Although various dimensions (environmental, social, logistical and technical) are not all related to the cost of an unpaved road, they are, in a context of sustainable management, very important dimensions to consider in an unpaved road network maintenance management.

Finally, a verification of the proposed solution will also be conducted as a case study. This verification is based on CARRLo project field tests which were realized with the collaboration of industrial partners.

The maintenance management decision support system for unpaved road network will propose one or more detailed solutions that meet specific needs and that are adapted to a specific context. Afterwards, these solutions will be verified by a case study using field tests and data supplied by an industrial partner.

5. METHODOLOGY

At first, the results of the study on the influence of mineralogy and grading on the performance of a granular material stabilized or treated with dust suppressants are presented. These results are used to build a database for the decision support system. In a second time, the environmental impacts of stabilization agents or dust suppressants on an unpaved road are also presented. Then, the multicriteria analysis is explained in detail. Finally, real section stabilization is presented. These field test results will be used in order to verify the decision support system.

5.1 Considerations regarding mineralogy and grading

In the CARRLo project, a major laboratory experimental program that includes resilient modulus, bearing capacity, cohesion and shear strength tests was conducted in order to be able to understand and then take into account the influence of mineralogy and grading on the performance of granular materials stabilized or treated with dust suppressants [14] [15]. The aim of this work is to be able to propose different type of stabilization agents or dust suppressants for a particular gradation and mineralogy aggregate context and according to specific objectives.

The results of this laboratory work have already been extensively studied [16]. They show a real influence of gradation and mineralogy on the performance of granular materials stabilized or treated with dust suppressants. Moreover, with the complete analysis of the experimental work performed, different types and concentrations of products can be suggested in order to maximize the performance of granular material stabilized or treated with dust suppressants.

The entire analysis of the experimental work carried out [16] will not be discussed in this article. For each mineralogy studied, charts showing the optimal concentration of various products depending on the particle size were made. Figure 2 shows an example for the granitic gneiss mineralogy. The conclusions of this work will be incorporated into the expert system (see figure 1) which will provide a list of solutions for the maintenance of a rural unpaved road in a specific gradation and mineralogy aggregate context.

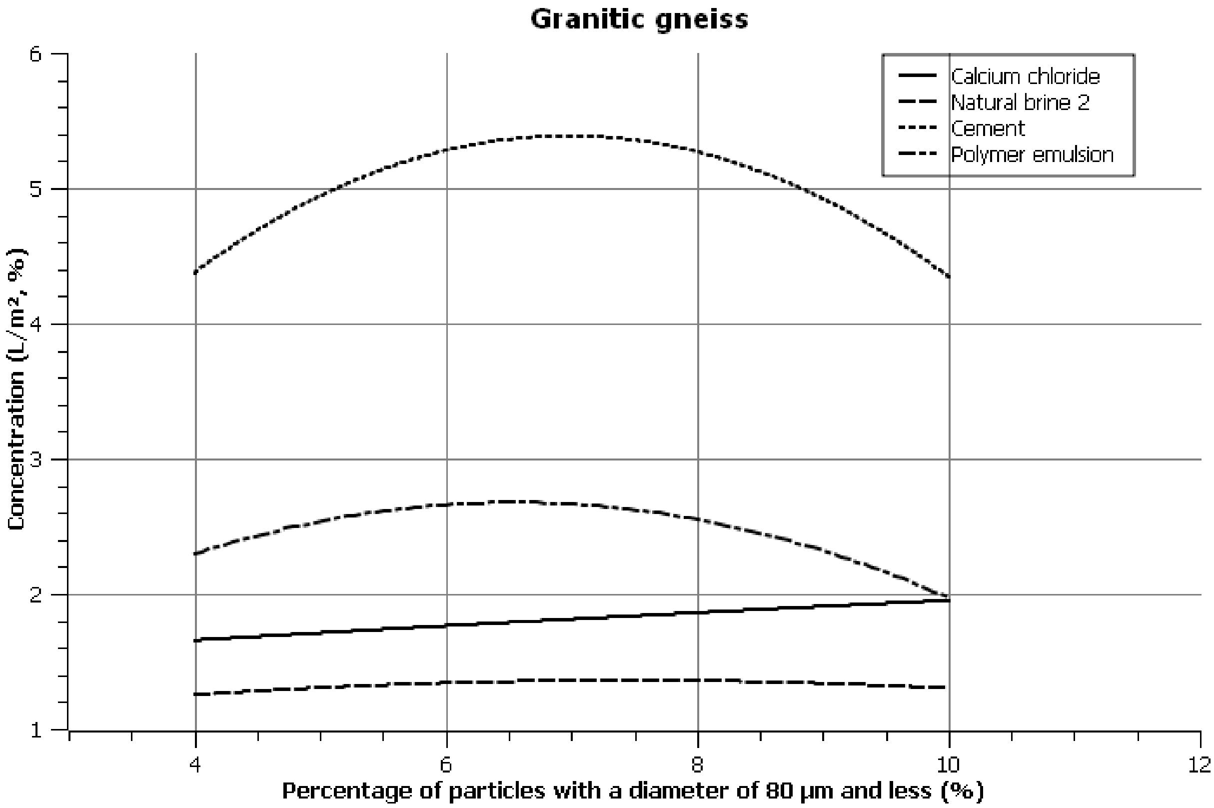

Figure 2 : Chart of optimal concentrations for various products (stabilization agents or dust suppressants) depending on particle size for granitic gneiss mineralogy

5.2 Environmental considerations

The application of stabilization agents and dust suppressants on unpaved roads has some environmental advantages [17] such as the reduction of dust which is caused by traffic or the reduction of sediments which are washed and then move from the road to the streams and lakes [18]. The application of these products also carries environmental risks which must be considered before the application such as negative impacts on fauna, flora, groundwater and rivers [19]. Indeed, after the products were applied, they are subjected to weather conditions and can spread in nature.

The water quality from sections treated with dust suppressants has been observed on two test sites in the CARRLo project. One of the test sites was the Montmorency forest, an experimental forest managed by Laval University situated at approximately 70 km north from Quebec city. The other test site was directly on the campus of Laval University. The results for these two test sites being very similar, only the results from the work done at Laval University in summer 2009 are presented in this article. They confirm the results obtained in summer 2008 at the Montmorency experimental forest site [17].

5.2.1 *Tests presentation*

Table 1 shows the products and their concentration which were tested at Laval University in summer 2009.

Table 1 – Type and products tested at Laval University in summer 2009.

Type	**Products**	**Concentration (l/m²)**
Hygroscopic	Natural brine 1	2
	Natural brine 2	1,5
	Calcium chloride	1,8
Organic	Natural emulsion	3,4
Synthetic	Polymer emulsion	3,4
	Vegetal polymer	3,6

Runoff and percolation waters have been collected and different tests have been performed to evaluate the impact of dust suppressants on the environment. Reclamation systems made at Laval University were installed to collect runoff and percolation water from each tub. Figure 3 shows the experimental setup for the runoff and percolation water reclamation systems. After each rain, a sampling of each tub was made. The reclamation systems were then emptied and replaced. Runoff and percolation water have been collected independently and submitted to various tests to assess the impact of dust suppressants on the environment.

Figure 3 – Runoff and percolation water reclamation systems at Laval University

Firstly, pH is the abbreviation for potential hydrogen. Il represents the concentration of H^+ in a liquid solution. This concentration of H^+ ions determines if water is acidic, neutral or basic (alkaline). The scale of pH is 0 -14. Neutral is defined as 7.0. Acidic pH is under 7.0 and alkaline and/or basic is over 7.0. This is one of the most important parameters to measure because many biological processes depend on the pH. In addition, it plays a major role in the blood system of aquatic organisms which can be seriously affected by fluctuations of the pH.

Secondly, carbonate hardness test (commonly referred to as alkalinity) is a measurement of the capacity for water to neutralize an acid, known as the buffering capacity. Values below 60 mg/l of $CaCO_3$ are normally associated with low pH which is good for fishes. Carbonates are also used by plants in photosynthesis to replace carbon dioxide.

Thirdly, total hardness test is a measure of all the dissolved salts in the water which are principally composed of calcium (Ca) and Magnesium (Mg). Values below 60 mg/l of $CaCO_3$ indicate soft water, values until 100 mg/l correspond to slightly hard water, values between 100 and 200 indicate moderately hard water and values up to 200 mg/l define very hard water. It is necessary to analyze this parameter because the concentration of dissolved salts affects the fish osmoregulation system and the calcium regulation levels in the blood.

Finally, the test for the presence of ammonia is achieved. Generally, the amount of ammonia (NH_3) should not exceed 1.2 mg/l. Levels up to 1.2 mg/l in very alkaline water (above 8.0 pH) are quite toxic to aquatic organisms. Ammonia can be present in two forms. Ammonia (NH_3), which is a toxic gas and ionic ammonium (NH_4^+), which is less deadly. The pH of the water is the major factor that determines the ratio of NH_3 and NH_4^+.Bacterial flora normally converts ammonia into nitrate to maintain a balance.

5.2.2 *Results presentation*

The tests performed were used to evaluate the runoff and percolation water samples from unpaved road sections treated with dust suppressants. It should be notice that rainfalls during summer 2009 were similar to monthly averages as shown in figure 4. During the summer, 19 samples were collected. The results for each test are shown in table 2. For each test, an average of the 19 samples was performed.

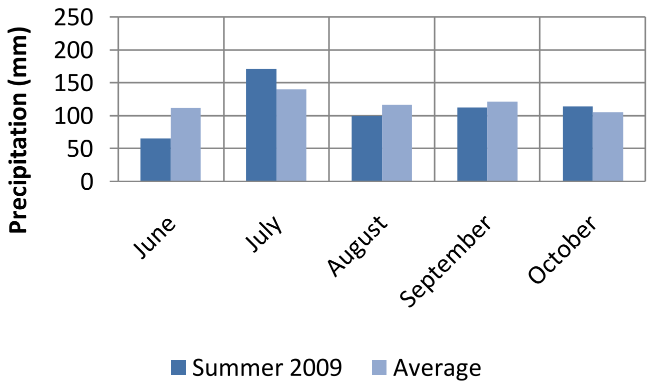

Figure 4 – Precipitations during summer 2009 at Laval University

Table 2 – Result of the tests performed during summer 2009 at Laval University for each product

	Water tested	pH	Carbonate hardness (mg/l $CaCO_3$)	Total hardness (mg/l dissolved salts)	Ammonia (mg/l NH_3)
Control	Runoff	6,1	21,3	35,0	0,2
	Percolation	7,2	53,3	88,3	0,0
Natural brine 1	Runoff	5,3	16,7	26,7	0,3
	Percolation	7,1	40,6	1669,4	0,2
Natural brine 2	Runoff	5,5	17,5	26,7	0,1
	Percolation	7,2	41,1	1702,2	0,3
Calcium chloride	Runoff	6,0	18,9	193,3	0,2
	Percolation	6,5	34,4	4296,4	0,4
Natural emulsion	Runoff	5,5	18,3	20,0	0,3
	Percolation	7,2	57,8	82,2	0,1
Polymer emulsion	Runoff	6,0	52,5	90,0	2,1
	Percolation	7,1	47,8	87,8	0,0
Vegetal emulsion	Runoff	5,3	16,7	13,3	0,1
	Percolation	7,3	87,2	227,8	0,4

Table 2 shows the pH average for the water collected from each road section. There is a significant difference between the runoff water and the percolation water collected for each road section treated with the different products. Indeed, all the percolation waters keep a neutral pH close to 7 while the runoff waters, including this linked to the control section, were all acidic. The acidic rain may explain these results which do not seem directly related to the nature of the products. The vegetal polymer and the natural brine 1 deal with the most acidic runoff waters while no product seems to have any impact on the pH of percolation waters.

For its part, the carbonate hardness should normally be above 20 mg/ℓ to effectively stabilize the water pH. This is particularly important in this case where all runoff waters are acidic. Therefore, the carbonate hardness average values for runoff waters of granular materials treated with vegetal polymer and natural brine 1 are the lowest which correspond with the lowest pH in table 2. On the contrary, percolation water from the road section treated with vegetal polymer which shows the highest pH also shows the highest carbonate hardness. The control road section and the one treated with vegetal polymer are the only one which shows satisfying results for its runoff water.

For total hardness, hygroscopic products which are rich in dissolved salts showed the highest rates. Calcium chloride gets, for percolation water, a very high total hardness average even if a reclamation system break has prevented sampling water when the rates were highest. Natural brine 1 and natural brine 2 also keep high averages above the 200 mg/l limit which corresponds to very hard water. Once more, the total hardness results for percolation and runoff waters were different.

Finally, for the ammonia rate, only the runoff water of the road section treated with polymer emulsion maintained an average above the recommended limit which is 1,2 mg/l of ammonia (NH_3).

5.3 Multicriteria analysis

The selected solution for the maintenance of an unpaved road network will essentially depend on the preferences of the road network manager that are linked to environmental, social, logistical and technical dimensions. Table 3 presents these dimensions.

Table 3 – Environmental, social, logistical and technical dimensions

Dimensions			
Environmental	Social	Logistical	Technical
Air quality Water quality	Influence on surrounding populations Influence on accidents	Influence on road transport Influence on road properties and services Road praticability	Road life Bearing capacity Road surface quality Maintenance frequency

Logistical and technical dimensions represent the two road network management levels : the logistical level and the technical level. Logistical level refers to planning and implementation of road network properties and services while technical level refers to various field operations and road characteristics.

In addition, some dimensions do not result in monetary benefits, but participate in getting a more sustainable road network management. For example, the fact that a product does not affect the runoff water quality of an unpaved road may be, in some contexts, a sufficient reason to choose this product because it keeps the nearby fauna and flora intact. So, in addition to logistical and technical dimensions, the decision support system also includes environmental and social dimensions.

Based on various dimensions presented in table 3, a multicretiria analysis will be performed. The multicreteria analysis method chosen is a pairwise comparison. This method represents the decision problem using a structure that reflects the interaction between different system components. It has four steps [20] : structure the problem hierarchically, perform dimensions pairwise comparison, give a relative weight to each dimension and rank the dimensions according to user priorities. The hierarchical structure of the decision problem is shown in figure 5.

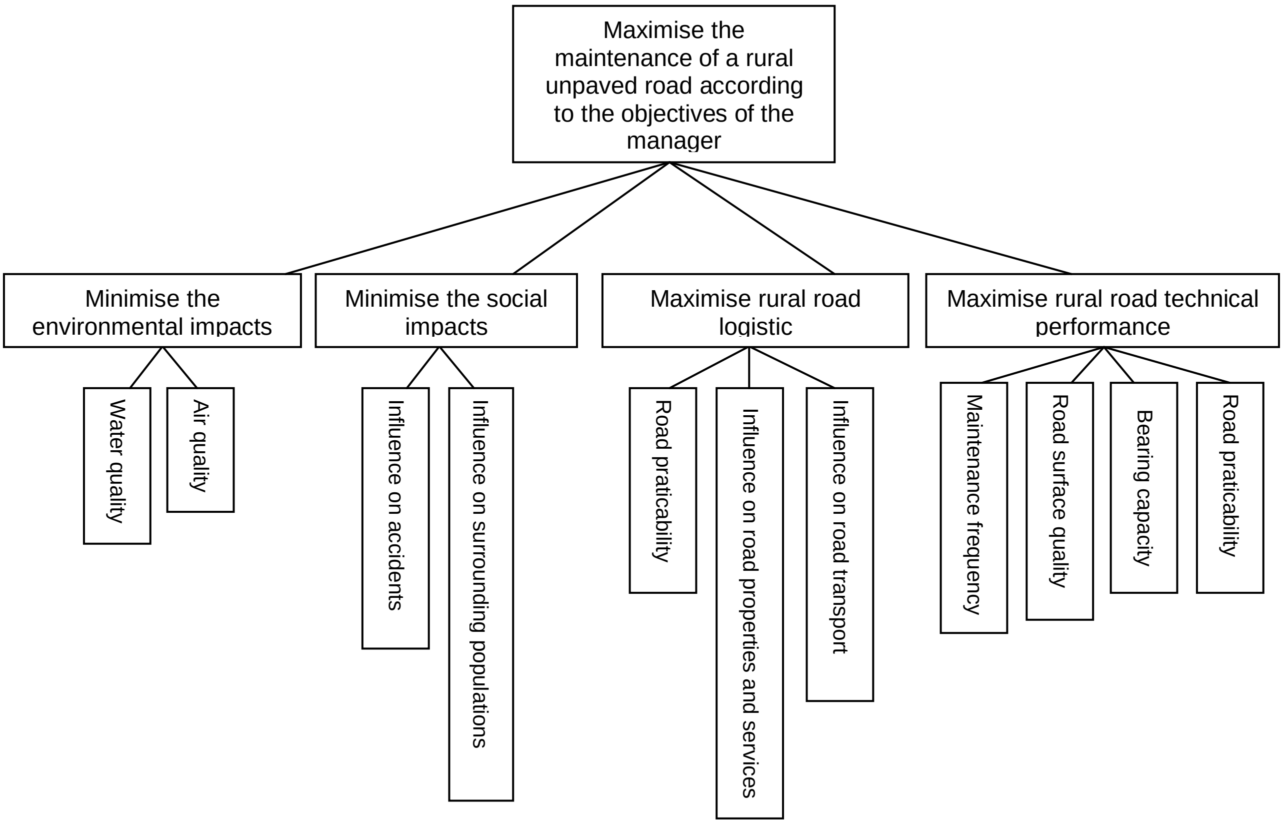

Figure 5 – Hierarchical structure used to maximise the maintenance of a rural unpaved road according to the manager objectives

The decision problem involving four dimensions, there will be six pairwise comparisons:

1. What is the relative importance of minimizing environmental impacts compared to minimizing social impacts in order to maximize unpaved rural road maintenance according to the manager objectives?
2. What is the relative importance of minimizing environmental impacts compared to maximizing road logistics in order to maximize unpaved rural road maintenance according to the manager objectives?
3. What is the relative importance of minimizing environmental impacts compared to maximizing road technical performance in order to maximize unpaved rural road maintenance according to the manager objectives?
4. What is the relative importance of minimizing social impacts compared to maximizing road logistics in order to maximize unpaved rural road maintenance according to the manager objectives?
5. What is the relative importance of minimizing social impacts compared to maximizing road performance in order to maximize unpaved rural road maintenance according to the manager objectives?
6. What is the relative importance of maximizing road logistics compared to maximizing road technical performance in order to maximize unpaved rural road maintenance according to manager objectives?

For these six comparisons, a relative weight will be assigned to each of the two dimensions compared. The summation of the relative weights will rank the dimensions according to the preferences of the unpaved rural road manager. Knowing the manager preferences, a solution will be selected from the list of solutions provided by the decision support system.

5.4 Decision support system verification using a field case study

According to figure 1, the decision support system is made of an expert system, an economic filter and a multicriteria analysis that depend on several experimental variables and environmental, social, logistical and technical dimensions. This decision support system provides a solution for rural unpaved road maintenance which will be subsequently verified by field tests under real conditions.

The verification of the selected solution from the list of solutions provided by the decision support system will be made as a case study. Using a complete database provided by an industrial partner and field tests carried out under controlled conditions, it will be possible to point out the advantages associated with unpaved road maintenance. Field tests consisting in producing treated road sections have already been performed under the CARRLo project. Sections monitoring was done using a portable Ligth Weight Deflectometer (LWD), a non destructive unit that reproduces, under the impact of a falling weight on the surface of the road, load corresponding to a vehicle.

5.4.1 *Field tests achievement*

Under CARRLo project, field tests in real conditions were performed in summer 2008 and summer 2009. For example, in summer 2008, a pronounced curve that always deteriorates very quickly, has been stabilized with polymer emulsion. Two sections of approximately 250 meters have been realized. The pronounced curve was treated with polymer emulsion while the other section, the control section, was not treated.

It should be noticed that these two sections were separated by a buffer zone of 500 meters to avoid contamination. It is also important to mention that before the realization of the sections, the unpaved road has been reloaded with a MG-20 granitic gneiss according to Quebec Ministry of Transport (MTQ) [21].

The section stabilized with polymer emulsion was made by removing a layer of about 5 cm of granular material and then by applying the product at a concentration of 3,4 l/m². Thereafter, the layer previously removed is replaced back. Finally, polymer emulsion is reapplied on the surface of the road, still at a concentration of 3,4 l/m². Laboratory results [22] [23] justify the concentration of polymer emulsion selected. In fact, a concentration of 3.4 l/m² contributes to improve more the mechanical properties of granitic gneiss than lower concentrations. Usually, the stabilization agent should be homogeneously mixed with granular material and stabilized to a depth of 10 cm. In this case, a concentration of 3,4 l/m² is applied to 5 cm deep and on the surface which is four times the concentration normally recommended. This major amount of stabilization agent is applied because of the hard road conditions (traffic consisting mostly of heavy loaded trucks and section located in a slope with a pronounced curve), the hard climatic conditions (stabilization agent applied during a rainy period) and to compensate for the fact that the granular material is not perfectly mixed, a homogeneous mixture between the granular material and the stabilization agents in real conditions being very difficult, laborious, expensive and therefore unrealistic. Figure 6 shows the application of stabilization agent after removing approximately 5 cm of granular material from the left side of the road. The removed material is found as a swath in the middle of the path. After the application of the polymer emulsion to 5 cm deep, the granular material is replaced back and then the stabilization agent is applied on the surface of the road. The application of polymer emulsion to the left side of the road is then finished and the same steps are done to stabilize the right side of the road. Figure 7 shows the roller compactor used for the compaction. The use of this equipment is recommended when the road has been reloaded.

Figure 6 – Spreading of the stabilization agent at 5 cm deep on the left side of the road

Figure 7 – Roller compactor used for compaction of the control and stabilized section

5.4.2 Presentation of the field tests results

The portable FWD is made up of a load application system and three geophones. The load is applied using a mass that fall on a circular plate. Applied stress depends on the mass itself, its drop height and the radius of the circular plate. The load duration is about 20 msecond. The geophones are used to measure deflections and thus allow to measure a deflection basin. There is a 30 cm space between each of the three geophones. One of them is placed directly beneath the circular plate. Figure 8 shows the influence line below which 95% of the deflection takes place [24]. Indeed, the stress distribution under the circular plate can be estimated by a straight line with a 34° angle. This is a good approximation of the curve which 95% of the deflection occurs. Because of the stress distribution, the geophones away from the point of load application provide information on deep layers while the geophone located under the circular plate gives the maximum deflection. Therefore, this provides a good evaluation of the structural behavior of the road studied.

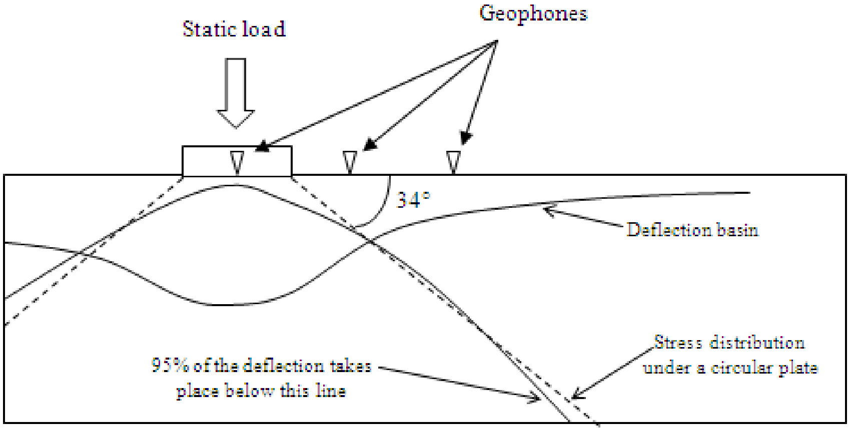

Figure 8 – Diagram of the influence line under which 95% of the deflection takes place

Figure 9 shows the deflections ratio at different depths of the control and stabilized sections over time. LWD tests were performed several times during summer 2008. The tests extend approximately from June 2008 to August 2008, for a total of approximately a hundred days. The results at 0 cm depth are provided by the geophone directly under the load that gives the maximum deflection of the road. The results at 10 cm and 30 cm depth are provided respectively by the geophones distant of 30 cm and 60 cm from the load application. With these results, the deflection of the road can be evaluated in depth. It should be noticed that lower the deflection is, greater the stiffness of the road is. Lower deflection values for the stabilized section compared to control section are therefore expected. The dotted lines on figure 9 correspond to the average of the relative results in time for different depths.

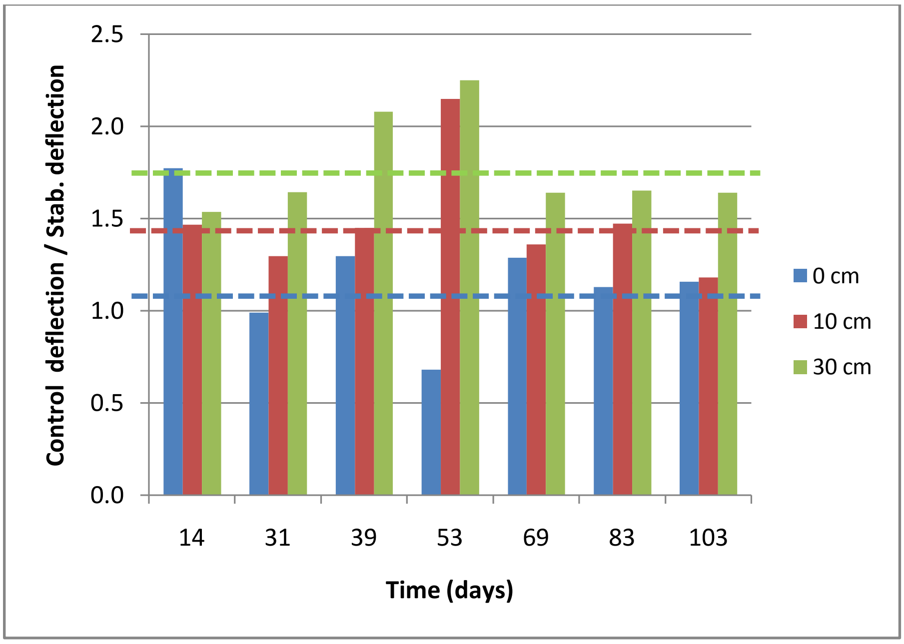

Figure 9 – Relative results for deflections versus time at different depths

By analyzing figure 9, it is clear that stabilization using the polymer emulsion reduces the deformation of the road deep. Indeed, the stabilized section has deflections 1.8 times lower than the control section at a depth of 30 cm and deflections 1.5 times lower than the control section at a depth of 10 cm. Moreover, as shown in figure 9, the results are relatively constant over time. This means that the stabilization agent, polymer emulsion, remains effective for at least 100 days after its application.

Therefore, it will be possible with the results from the stabilized section monitoring described above and using a complete database provided by the industrial partner, to validate the technical solution provided by the decision support system and evaluate if the manager objectives have been met.

6. CONCLUSION

The research presented will facilitate the work of rural unpaved road network managers. It will help them to rigorously manage the maintenance of their road network according to their preferences. The innovation of this project is the personification of the solutions for different types of users and according to the goals and preferences of the managers of these networks.

The main features of the road network and various experimental variables (type of granular material, product type for stabilization or dust suppressant treatment) will be integrated to the decision support system that will provide various solutions. A study of the previous experimental work [14] [15] [17] [22] [23] [25] will allow the proposition of stabilization agents or dust suppressant and their concentrations adapted to the road characteristics and experimental variables.

The features of the road network will also be taken into account. Some rural networks may for example be used mainly for private properties access while others are mainly used to deflect the heavy transport from a municipality. Taking into account the manager needs will target the best solutions based on his objectives.

Secondly, the list of solutions proposed by the expert system is then submitted to an economic filter to ensure that they respect the budgetary constraints of the rural road network manager. To do this, the parameters having the most influence on the costs of unpaved road network maintenance were targeted. Thus, some maintenance solutions too expensive will be eliminated by the economic filter.

Then, various environmental, social, logistical and technical dimensions will be introduced. For example, the impacts of spreading stabilization agents or dust suppressants on water quality (environmental dimension) or on the reduction of accidents (social dimension) will be evaluated. Using a multicriteria analysis method, weights will be assigned to each dimension. A list of solutions that meets the manager preferences and objectives will then be targeted.

Finally, through a case study, a validation of the final solution will be made. Using a complete database collected during field tests, it will be possible to bring out the advantages associated with unpaved road maintenance. Sustainable management of rural unpaved roads as presented in this paper introduces an innovative and rigorous way of thinking and managing this type of road network according to the manager preferences and objectives.

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