

THE USE OF GRAVEL LOSS PREDICTING MODELS FOR EFFECTIVE MANAGEMENT OF GRAVEL ROADS

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ABSTRACT

To conserve the gravel materials borrow pits (B/P) and gravel materials deployed as surfacing layer of unsealed roads, there is a need to reduce regravelling cycles to optimum level. This can be achieved by reducing the rate of gravel loss (GL) through quantifying locally, the annual GL and addressing factors behind it. Understanding the behaviour of local gravel materials to readily lose fines followed by coarser particles under the action of traffic and climate is of paramount importance in achieving the above goal.

This paper advocates the use of the gravel loss predicting model (GLPM) as one of the measures of conserving gravel wearing course and gravel B/P and hence towards effective management of gravel roads. The GL information, as captured by GLPMs, formulated through monitoring GL over the passage of time, will assist those responsible in managing gravel roads to address the root causes of GL and hence reduce the grading and regravelling frequencies.

1 INTRODUCTION

Due to weak forces binding the gravel wearing course, all gravel roads will lose their surfacing materials with time. The loss will be through combined action of climatic erosion and vehicle attrition. The loss varies in rate, quantity and extent depending on materials characteristics, type of terrain, design, construction and maintenance standards. The more appropriate the standards to the local condition the less the loss will be.

Reducing the rate of GL is beneficial not only in lowering maintenance costs, but in placing less demand on “winning” gravel, reducing dust emissions, less surface ravelling, better ride qualities and improved road safety (Henning et al, 2008). The slowing down of GL is possible only when one is able to predict accurately the rate of GL annually. This can only be achieved through empirical studies. The exercise can also give clue to the causes attributing to the amount of GL obtained and appropriate maintenance actions to be taken.

The time span between the onsets of GL process to the time when the subgrade is exposed is a very paramount period for preventive maintenance decisions. Various maintenance activities are appropriate at different stages of this process. These activities begin with those of preventive in nature. Once that appropriate window for the preventive maintenance activities has passed, the next activities will cost dearly. Under effective management of gravel roads, the preventive maintenance activities have to be encouraged by using proper gravel roads management tools. One of them is GLPM.

1.1 Problem statement

In most sub-Saharan Africa, it is proving challenging for gravel roads maintenance to be programmed objectively and carried out effectively under competing demands for limited resources. Road agencies in these countries must search for the most appropriate tools in design, construction and prioritising maintenance practices of gravel roads. One of these tools is a dynamic GLPM which can be used to assist asset management processes, and to reduce GL through improved design, construction and maintenance practices.

Knowing the variation rate of GL, as captured by the GLPMs, could aid in mitigating its impacts during design, construction, and maintenance periods. The knowledge could also assist in arriving at correct and appropriate conservation program for gravel roads and gravel materials B/P.

1.2 Objective

The general aim of the paper is to improve the performance of gravel roads, by suggesting measures to slow down the rate of GL.

The information embedded into GL is complex, and is caused by many factors. These factors are i. type of terrain, ii. variation in traffic volume, composition and loading, iii. drivers' behaviour, iv. seasonal climatic changes, v. initial gravel wearing course thickness, vi. gravel and subgrade materials properties, vii. design, construction and maintenance standard, viii road geometry, and ix. road drainage. The primary objective of this paper is to explore GL information, which will lead to effective management of gravel roads.

1.3 Scope

This paper limits itself on the causes of GL and uses of GLPM. Also it attempts to explain how GLPM can be used to inhibit GL. Modelling exercise is just briefly mentioned without going into its detail.

2 **GRAVEL ROADS**

Gravel roads have a wearing course of imported unbound gravel materials which are typically constructed to a specified standard. These roads are required to provide an all weather surface. The behaviour of gravel wearing course will depends on factors listed under sub heading 1.2, second paragraph.

2.1 Maintenance management

Maintenance is essentially a management problem. The improvement of maintenance often involves institutional reform, human resource development and changes to management practices before addressing technical issues. The task of managing a gravel road in an optimal manner still remains a technically complex one. This task can be greatly simplified by employing appropriate engineering management techniques.

2.2 Gravel roads management as an engineered management system

An engineered management system (EMS) is defined as a system that consists of a set of engineering tools for performing condition surveys and prediction. Also EMS is involved in developing work plans with the objective of optimising spending. EMSs uses engineering technology to determine, when, where and how to best maintain facilities. They provide the needed leverage to preserve the infrastructure investment (Shahin, 1994).

2.3 Gravel roads preventive maintenance

Preventive Maintenance (PM) is a cost-effective strategy of early maintenance done to a gravel roads pavement as a pre-emptive measure to preserve the pavement by retarding deterioration. PM is traditionally a low-cost treatment done early in a pavement's deterioration cycle. By definition, pavement PM extends the service life and maintains the functional condition of the system without substantially increasing structural capacity. Gravel roads PM activities maintain the cross sections to keep water out and reduce the amount of water infiltrating the pavement structure and correct non-load- related surface deficiencies. If applied at the proper time, gravel roads PM will lower the life cycle cost of any given pavement section, and when applied on a gravel road network will improve the system condition at a lower cost (Morse and Green, 2009).

2.4 Gravel loss

GL is one of the modes of gravel roads deterioration of primary relevance to the management of gravel roads (Paterson, 1991). According to Gichaga and Parker (1988) GL refers to the amount of material that has been swept away and which it is necessary to replace in order to restore the original road geometry; it is measured in average millimeters thickness, GL is taken as one of the physical challenges associated with maintenance of gravel roads surface. GL can be defined as a time-dependent reduction of the thickness of a gravel layer by the mechanical removal of gravel material from the road prism to the immediate surroundings of the road (Dierks, 1992), or change in average gravel thickness over a period of time (Paterson 1991). Gravel materials is lost by the actions of scouring, kick off, dust, attrition, stones breaking down through the passage of heavy vehicles and by traffic pushing gravels into the weak subgrade (Henning, et al, 2008).

The rate of GL depends on the rainfall, and traffic characteristics; also on alignment gradient, surface cross fall, road width, material quality, compaction and maintenance practices (World Road Association, et al, 2002).

GL causes gravel surfaced roads to be susceptible to rutting under traffic (Uys, 2008) and raise the risk of losing passability in wet conditions. It is a primary determinant of the timing of regravelling operations.

Parameters influencing GL can be grouped into five categories, namely i. Road surface distress, ii. Traffic, iii. Environmental and types of terrain, iv. Road geometry and Drainage, and v. Vehicle characteristics. Following is the brief description of each parameters and its remedy.

2.4.1 Road surface distress

Typical road surface distress which affect GL are dust, ravelling, erosion, and the GL.

2.4.1.1 Dust

Dust is the release of fine material from the road surface, of which silt sized particles (5 – 75 µm) are the predominant elements. The quantity of dust generated by a vehicle is a function of its aerodynamic shape, speed of travel and the surfacing material properties, and that generated by wind is a function of wind speed, surface condition and trees cover. Dust is an important form of GL. The major characteristics affecting dustiness are vehicle volumes mix and speed, moisture content of the road, looseness of the material, maintenance frequency and wind speed (TRH 20, 2009). Research has shown that the probability of dust being acceptable is highest when the Shrinkage Product (SP) [SP is the product of linear shrinkage and percentage passing 0.425 mm sieve] is restricted to values between 120 and 400 (United Republic of Tanzania, 1999).

2.4.1.2 Ravelling

Loose gravel may be generated as the result of ravelling. Ravelling is mainly caused by a deficiency of fine material, and hence cohesion, a poor particle size distribution and inadequate compaction. Material with Grading Coefficient (GC) [GC is the product of the difference in percentage passing 28 mm and 0.425 mm sieves and the percentage passing the 5.00 mm sieve expressed as a percentage] in excess of 34 and/or a SP of less than 120 are particularly prone to ravelling (United Republic of Tanzania, 1999). Fine material can be blended with the gravel to increase cohesion. Compaction at Optimum Moisture Content (OMC) can be used to cut down on ravelling (TRH 20, 2009).

2.4.1.3 Erosion

Erosion is the loss of materials caused by the flow of water. Resistance against erosion depends on the shear strength of the material in relation to the tractive forces induced by the water. Materials with GC less than 16 are particularly susceptible to erosion, compared to material with a high plasticity, which may resist erosion. Erosion could be prevented by increasing the shear strength of the material or by decreasing the shear stresses induced by the water flow through retarding the rate of flow. The shear strength can be increased by ensuring a well-graded, cohesive mixture is used, and by decreasing the permeability of the material through adequate compaction. The shear stress can be decreased by decreasing the grade and the cross-fall and ensuring that the length of the flow path of the water is minimised (TRH 20, 2009).

2.4.1.4 Gravel loss

The loss of gravel materials from the road surface is caused by traffic and climatic conditions. Materials that ravel most are likely to result in a high GL. According to Uys (2008) GL can be reduced by selecting a material with a suitably high Plastic Factor (PF) (PF greater than 500) and percentages passing the 28 mm sieve. Well graded gravel materials resist GL better than materials deficient in either fine or coarse fractions, even if they are well compacted (TRH 20, 2009).

2.4.2 Traffic

2.4.2.1 Traffic compaction

Gravel roads wearing courses which have been compacted with a nominal number of passes of a grid-roller can lose up to 30 per cent of the construction thickness within a short period of time due to traffic compaction (Paige-Green, 1989). It is therefore important to ensure adequate compaction by using appropriate type of roller or cover the loss caused by traffic compaction in the thickness design. Local experience and field trials may be necessary to quantify an approximate estimate for the potential traffic compaction.

2.4.2.2 Traffic growth rate

The rate of growth of traffic from one volume level to another would affect the rate of GL of a particular type of gravel materials. Once established for a particular traffic volume, the correlation between the traffic growth rate and the GL can be established through a consistent monitoring exercise.

2.4.2.3 Traffic volume, composition and loading

Traffic volume data, indicating the type and proportions of the vehicles making up that volume, is normally associated with gravel roads performance study. These data form a part of variables used in correlations with the amount of GL obtained in the study. In most of gravel roads, traffic loading is visually observed rather than measured.

2.4.3 Environmental

The structural layers of unsealed roads are directly exposed to environmental forces which can have a rapid effect on GL. The local climatic region data, particular rain, wind, terrain type, do have influence on gravel roads performance. These data are part of variables used in correlating with amount of GL to derive the GLPMs.

The terrain type is defined by gradient and/or curvature. Type of terrain, in terms of gradient, affect the speed on which the gravel materials will be lost through interaction with water.

2.4.4 Road geometry and drainage

Road geometric is concerned with those elements which make up the visible features of the roadway. These features are horizontal and vertical curvature, the cross-sections elements, longitudinal grades, and the layout of intersections. The geometric features influencing gravel loss are horizontal and vertical curvature, the cross section elements and longitudinal grades. Geometric cross-sectional characteristics particularly crown, camber, table side-drains and run-off points have pronounced effects on drainage and gravel road deterioration during high rainfall. Longitudinal-section, in particular the grade above 6%, interacts with rain water to cause GL. Horizontal curvature not in harmony with vehicle speed will create gravel materials whip off, and vertical curvature with steep grades will interact with rain water to erode the gravel materials.

In material loss prediction the horizontal curvature affects the rate of traffic-induced material whip-off and the longitudinal gradient interact with rainfall in causing erosion.

2.4.5 Vehicle shear stress characteristics

Vehicles shear stress characteristics vary with type and model. They are five types of vehicles, namely i). high and ii) low performance passenger's cars, iii) buses, iv) heavy single unit trucks, and v) trailer trucks. Gravel roads are directly influenced by the direct forces of wheels on the road which generate shear stresses. These shear stresses are generated not only when vehicles are in uniform motion but also during acceleration, braking and cornering. These stresses vary with the power and mass of vehicles using the road.

3 MODEL

A model is a representation of a system that allows for investigation of the properties of the system, and in some cases, predicts the future outcomes. In the model the real situation is simplified by leaving out those aspects that are not important for whatever is being investigated. As a result what is a good model depends on what it is used for and how accurate the prediction or calculation should be (Austin & Burns, 1985; Gichaga & Parker, 1988). The output from models must be recognised exactly for what they are - information

based on a simplified representation of reality. Seldom or never can all constraints affecting gravel roads performance be included in a mathematical programming model of the problem.

3.1 Prediction models

Prediction models can be classified as either probabilistic or deterministic. Depending on the modelling preference, GLPMs can be formulated by using either probabilistic or deterministic modelling principles.

3.1.1 *Probabilistic model*

Probabilistic model is a statistical analysis tool that estimates, on the basis of past data, the probability of an event occurring again. Probabilistic modelling is any form of modelling that utilises presumed probability distribution of certain input assumptions to calculate the implied probability distribution for chosen output metrics.

3.1.2 *Deterministic model*

Deterministic model is a mathematical model in which the outcomes are precisely determined through known relationships among states and events, without any room for random variation. According to Austin & Burns (1985), when the problem can be characterised with certainty, it is referred to as deterministic.

These models are developed from empirical or mechanistic empirical models which do not explicitly consider uncertainty. Future performance owing to deterioration and maintenance activities is therefore assumed to be certain.

4 USES OF GRAVEL LOSS PREDICTING MODEL

Following are the uses of GLPMs as a tool for effective management of gravel roads. These uses are based on life cycle approach rather than present condition and ad hoc approaches.

4.1 Gravel road management system

According to Shahin (1994) GLPMs are imperative for a complete gravel road management system. In the gravel road management system, GL prediction models are the driving force behind effective preventive maintenance.

4.2 Determining maintenance and rehabilitation requirement

Prediction models are used at both the network and project levels to analyse the condition and determine maintenance and rehabilitation (M&R) requirements. At the network level, prediction models uses condition forecasting, budget planning, inspection scheduling, and work planning. One of the most important network uses of prediction models is to conduct “what if” analysis- to study the effects of various budget levels on future pavements conditions.

At the project level, prediction models are used to select specific rehabilitation alternatives to meet expected traffic and climatic conditions. The models provide the major input to performing life-cycle cost analysis to compare the economics of various M&R alternatives.

4.3 Predicting the effects of proposed policies

It is important to be able to predict the effects that proposed policies are likely to have in the future. Such predictive capabilities enable the decision-maker to test alternative course of action to determine which policies and strategies will be the most effective in accomplishing the desired goals with the resources available.

4.4 Predicting the residual life of gravel roads

GLPMs are used to predict the remaining residual life of gravel road surface layer, by using data of distress survey, climatic, road alignment, traffic, and materials characteristics. Knowing the rate of GL, and the initial thickness of gravel wearing course, one will be able to accurately foretell the residual life of gravel road surfacing layer.

4.5 Evaluating the trade-offs between different maintenance and construction policies

The predicting model of GL is suitable for use in evaluating the trade-offs between different maintenance and construction policies. However, to employ this method requires good knowledge about the gravel materials being used and the rates at which they will deteriorate under different traffic levels and climatic situations. As the gravel road deteriorates, its GL increases and at, different level of residual gravel layer, different treatment become appropriate (Robinson et al, 1998). Also knowing the rate of GL of particular gravel materials, can assist in designing measures to control it during design, construction, and maintenance periods.

4.6 Establishing an economically defensible grading cycle

The GLPMs form the basis for the establishment of an economically defensible grading cycle based on cost-optimised arguments.

4.7 Inhibiting gravel loss

The knowledge of factors behind the annual rate of GL for the particular gravel materials can be used to inhibit GL at the design stage.

GL control measures have to be built at the design stage by selecting materials which when properly constructed and maintained can be able to withstand the combined actions of traffic and climate. According to Ferry, (1998) unsealed roads should be designed to withstand the effect of local climatic influence on GL. It is clear that through appropriate material selection and construction procedures, the performance of the unsealed roads can be improved and the consequent negative environment effects reduced.

4.8 Determining regravelling frequency

For a maintenance and rehabilitation management model, the life-cycle of deterioration and maintenance of gravel roads can be depicted by the downward trends in surfacing material thickness over time, as shown in Figure 2 (Paterson, 1991).

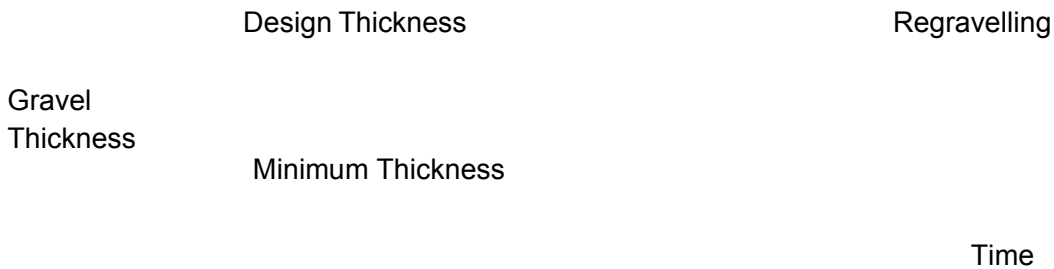


Figure 1: Trend of gravel material loss

Knowing the rate of annual GL and the life-cycle of the gravel road in question, will indicate the gravel material that will be lost over the design life of the road. Once the threshold level of a gravel layer residual thickness has been established, one will be in a position to calculate the regravelling frequency.

4.9 Gravel materials characteristics and specification

The characteristics of gravel materials to lose or retain for a considerable length of time its cohesive nature of holding down granular particles can be specified by using performance study.

Table 1: Tanzania Gravel Wearing Course Materials Specification

Maximum size	≤ 37.5 mm
Shrinkage Product	120 – 400
Grading Coefficient	16 – 34
CBR [%] at 95% of MDD (BS-Heavy Compaction)	≥ 25
Field Dry Density [% of MDD] (BS-Heavy Compaction)	≥ 95

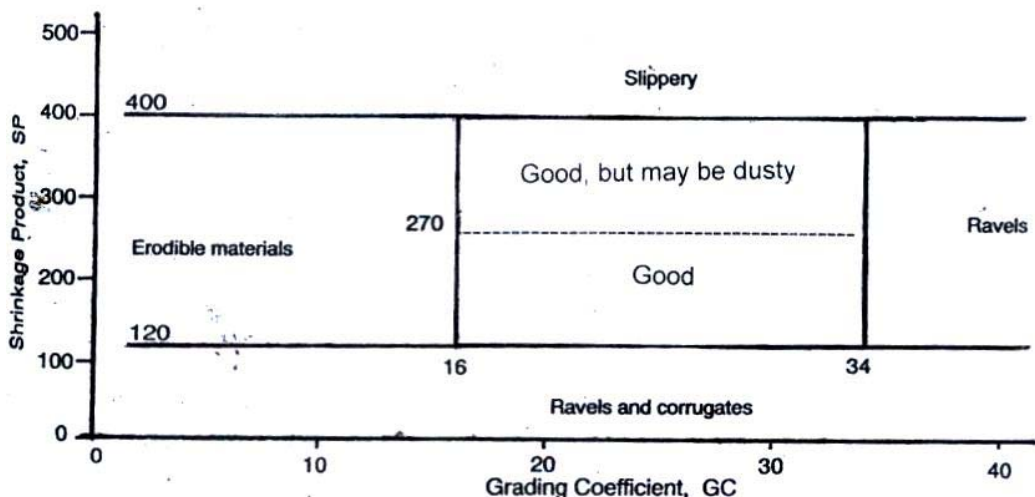


Figure 2: Relationship between shrinkage product and grading coefficient (Source: United Republic of Tanzania, 1999)

Dierks (1992) has stated that the derivation of appropriate specification for the selection of surfacing materials for unsealed roads can be derived locally from monitoring among other parameters the GL on a range of existing gravel roads, and correlating it with the materials physical characteristics. According to Paige-Green (2006) the current specification for unsealed roads in Southern Africa was derived from a large performance-related study of 110 sections of gravel roads carried out in 1989. The study correlated slippery, erosion, ravelling, and corrugation distresses with the GC and SP of the gravel materials used in surfacing layer. In the above listed surface distresses, ravelling and erosion are among those influencing gravel losses. The result of the said study, which was locally calibrated for Tanzania condition, are summarized in Table 1 (United Republic of Tanzania, 1999) and illustrated in Figure 2 above.

4.10 Gravel Materials Borrow Pits Management

Gravel Materials borrow pits management system requires among other things to determine the time at which the materials will deplete. The knowledge of the annual rate of GL of the gravel materials sourced from a certain B/P enable one to determine the effective life span of the said B/P, and set programmes to tackle the outcome.

4.11 Determining when the Gravel Road has to be upgraded

The amount of annual GL can be used as the basis to determine when it is economical for the road section in question to be upgraded to sealed pavement or set a threshold level of which to set regravelling cycle in motion.

5 STATUS OF GRAVEL ROAD MANAGEMENT SYSTEMS IN SUB SAHARA AFRICA

90 per cent of total road network in Sub-Sahara Africa are unsealed roads, surfaced with either natural soil or gravel materials. The GRMS in existence is mainly based on ad hoc and present condition approaches. Currently there is little or no effort directed towards formulating performance predicting models for addressing local condition. The research study, which is currently going on in southern Tanzania, is part of the effort aimed to address the situation.

6 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The economic use of gravel wearing course should be advocated by studying and incorporating into GLPMs, the impact of local climatic elements, traffic, local gravel and subgrade materials physical and mechanical characteristics on the performance of gravel wearing course. The knowledge gained will aid in optimum design, construction, and maintenance of gravel surfaced roads.

Predicting tools should be deployed to assist pavement maintenance engineers in establishing effective gravel roads management systems. GLPMs should be used as a tool to assist engineer in establishing and checking effectiveness of maintenance programme.

The limitation on continued growth and competence in solving gravel roads management challenges rests in part upon the modelling literacy of maintenance and rehabilitation engineers and prospective engineers.

6.2 Recommendations

The inherent challenges of gravel roads are:-

(1) Impassable during the rainy season, (2) Gravel wearing course is abraded by traffic and climatic elements, (3) Dust clouds develop in dry conditions, (4) Frequent grading by motor-graders is required to restore the riding quality, and (5) Regular regravelling depletes natural resources.

These challenges can be tackled to optimum level with properly formulated GLPMs which must:-

(1) Provide an indicative time frame of maintenance activities, (2) Provide effective guidance to maintenance personnel as to the appropriate action to be taken, (3) Be flexible to cover all ranges of local gravel road performance expectation, (4) Be able to indicate the nature of maintenance activity required at every stage of gravel loss quantification, (5) Indicate the nature of gravel loss, and the knowledge if it is economical to replenish or upgrade the road section to sealed pavement and (6) Assist in developing a universal yard stick for quantifying gravel loss, which shall be known as GL Index.

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