MANAGEMENT OF UNPAVED ROADS: DEVELOPING A STRATEGY AND REFINING MODELS

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ABSTRACT

The Western Cape has a large network of 25 300 km of unpaved roads. The unpaved road network is managed within the framework of the Unpaved Road Maintenance System with the assistance of five District Municipalities. The Road Network Management Branch is under continuous pressure to provide and maintain a safe and economic road network with limited funds. The Branch's objective for the unpaved road network is to maintain and build high performance and cost effective gravel roads that will last longer, provide a good average riding quality and a safe riding surface. Only a fraction of the gravel loss per annum has been replaced during the last decade, resulting in the average gravel thickness decreasing from 75 mm in 1990 to 23 mm in 2009 and remaining at that thickness since then. Consequently, there has been a significant increase in very poor roads. The poor state of the unpaved network makes it is imperative that the Branch use its available funding in the most effective and efficient manner through application of the best processes and technology. The objective of the paper is to present the approach taken by the Branch to develop and implement a turnaround strategy that includes the refinement of HDM-4 prediction models. The paper covers an introduction to the problem, describes the Unpaved Road Maintenance System, the strategy and plan, which includes the level of service and treatment activities for planned maintenance, the demand-supply model for determining the required supply of gravel and the number of regravel teams for a target average thickness of gravel on the network. The development of the strategy and plan enables the connection of tactical planning and operational maintenance activities with the strategic objectives and encourages discussion on cost, performance and risk to spur on improvements that should lead to better network performance. The revival and redevelopment of management information systems with improved modules and a new Risk Register module providing planning and operational support, and new functionality in the Materials Information Management System is described. Improving techniques and technologies through blading optimisation, crushing of material, rolling after blading, tyre dragging and blading maintenance strategy development is also covered. The calibration and adjustment of the HDM-4 performance models to incorporate the quality of construction, specific blading methods as well as other treatments is ongoing. The optimum maintenance strategy on a road could consist of different treatments during the

maintenance life-cycle and that different strategies are required depending on materials, climate, topography (horizontal and vertical alignment) and traffic. In conclusion, the significance of this work lies in the development of a strategy that enables the connection of tactical planning and operational maintenance activities on the unpaved road network with the strategic objectives and encourages discussion on cost, performance and risk, while spurring on improvements that lead to more effective management, better network performance and outcomes for the community.

1 INTRODUCTION

The road network in the Western Cape, comprising 16 300 km of trunk, main and divisional roads and 15 700 km of minor roads, but excluding the urban areas and the national roads, is owned and managed by the Roads Network Management Branch (‘the Branch’) of the Western Cape Government (WCG). Unpaved roads comprise 79% (25 300 km) of the road network in the Western Cape, South Africa, compared with 43% worldwide.

The Branch manages the unpaved road network, with the assistance of the five District Municipalities (DMs). The DMs carry out routine maintenance, i.e. blading, and periodic maintenance, i.e. regravelling, reworking and reshaping. Some periodic maintenance projects have also been carried out on contract, but due to the specification, size, risk and geographic location of these projects, the costs have been excessive and substantially more than the cost of work carried out by the DMs. Only a fraction of the gravel loss per annum has been replaced during the last decade. The result of under-funding is an average gravel thickness on the road network that decreased from 75 mm in 1990 to 23 mm in 2009, and remaining at approximately that thickness since then (Figure 1).

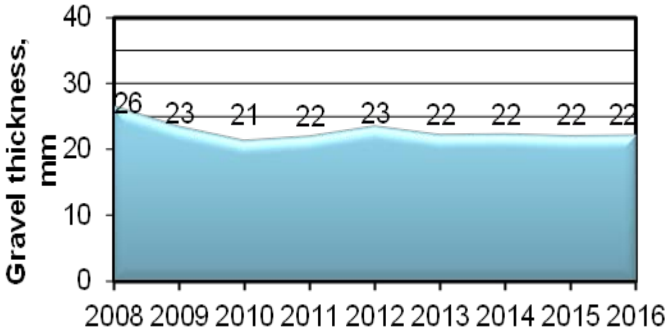


Figure 1: Average gravel thickness

The condition of the network (Figure 2) has worsened, with a significant increase in very poor roads since 2013. The downward trend in Network Condition Number (Figure 3), indicates an ongoing decline in condition.

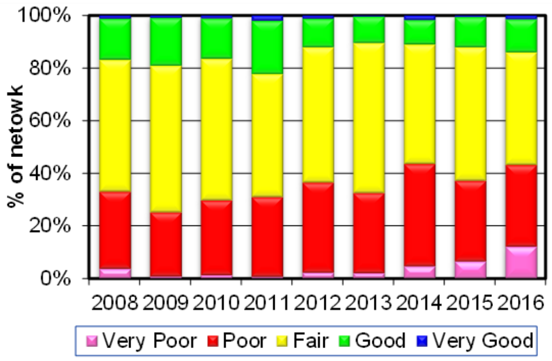


Figure 2: The visual condition of the unpaved road network over a period of 8 years

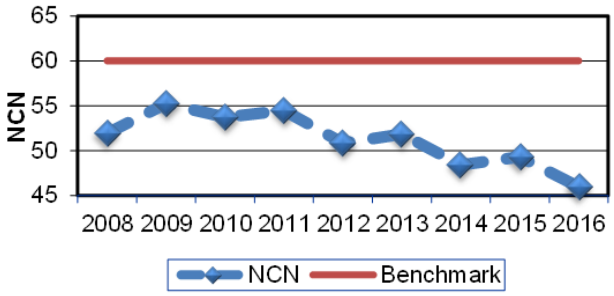


Figure 3: Trend in Network Condition Number over a period of 8 years to 2016

The Branch is under continuous pressure to provide and maintain a safe and economic road network with limited funds. It is imperative that the Branch use its available funding in the most effective and efficient manner through application of the best processes and technology for the maintenance of the unpaved road network. The Branch's objective for the unpaved road network is to maintain and build high performance and cost effective gravel roads that will last longer, provide a good average riding quality and a safe riding surface.

Many issues have contributed to the historically poor performance of the network, previously described by Henderson (Henderson & Van Zyl, 2004). Some of these issues were addressed through training, such as better construction methods. Many of the issues that had improved after these interventions re-appeared during a period of 7 years when staff shortages led to limited leadership and governance for gravel roads maintenance. Borrow pits (Western Cape Provincial Administration, 2006b) were not always used effectively

Changes to the law and regulations governing environmental, land use and mining approvals for the legalisation of gravel sources led to a situation where very few sources were legally compliant so that they could be mined. At least two years is needed for the process of legalising a gravel source. This situation led to a diversion of funding to the upgrading of unpaved roads.

Since March 2015, a renewed effort has been made to legalise material sources for periodic maintenance projects as well as for spot regravelling. However, efforts to establish a network of gravel sources have been complex and hindered by the lack of suitable gravel wearing course as a consequence of the underlying geology and predominantly mechanical weathering over the majority of the Western Cape. A lack of cooperation by some land owners, the need to avoid restricted areas containing endangered indigenous vegetation, nature reserves and national parks, as well as high value agricultural areas, have also hampered efforts to find gravel sources. However, some of the DMs have become resourceful in their efforts to maintain the unpaved road network by excavating material from cuttings, lowering the road in places where there were humps and using the accumulated windrows on both sides of the road to build up the roadbed. Reshaping of roads has also been done more effectively.

In order to address the issues in legalising material sources and managing the maintenance of the network the Gravel Management System (GMS) was created (Henderson & Van Zyl, 2004). A systems approach was followed to identify and to address all processes in the provision and maintenance of unpaved roads, while integrating with other management systems. Unfortunately, the GMS fell into disuse during the period of staff shortages and its importance in supporting the management of the network went unrecognised. A new Materials Information Management System (MIMS) was created, based on the borrow pit module that was originally part of the GMS, in order to store information on the sources of gravel and other road building materials. However, MIMS was divorced from the business processes associated with periodic maintenance, which it was supposed to support, resulting in a disjointed approach to the provision of gravel sources that did not provide the gravel required for priority periodic maintenance projects. In addition to the challenge of maintaining acceptable levels of service, the material sources suitable for gravel wearing courses are being depleted.

Recent environmental legislation further reduces availability of gravel. Several alternatives are currently being investi-gated to reduce the demand for material and to utilise reclaimed and non-standard materials to extend the time to total depletion. The principle and alternatives are shown in Figure 4.

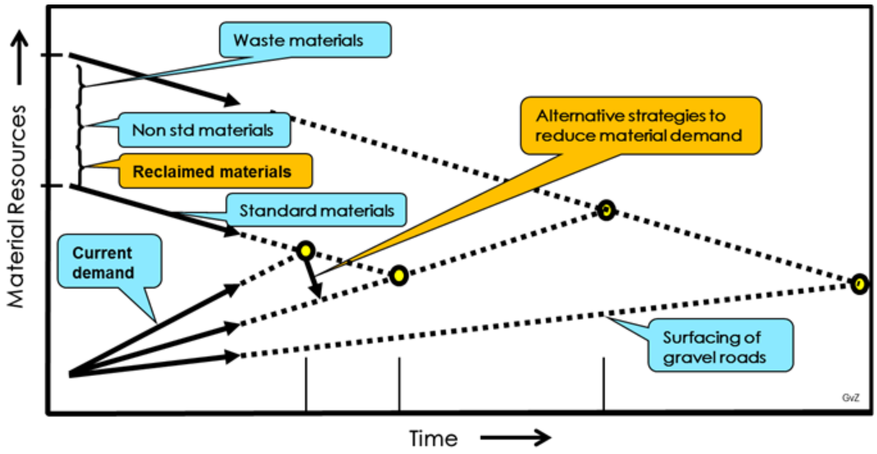


Figure 1: Strategies to extend the time towards depletion of materials

2 UNPAVED ROAD MAINTENANCE SYSTEM, STRATEGY AND PLAN

Good asset management connects operational work with strategic objectives (‘line of sight’). A strategic approach to unpaved road maintenance is critical for sustainability. The Unpaved Road Maintenance System (Figure 5) provides the framework for improving maintenance of the unpaved road network in the Western Cape.

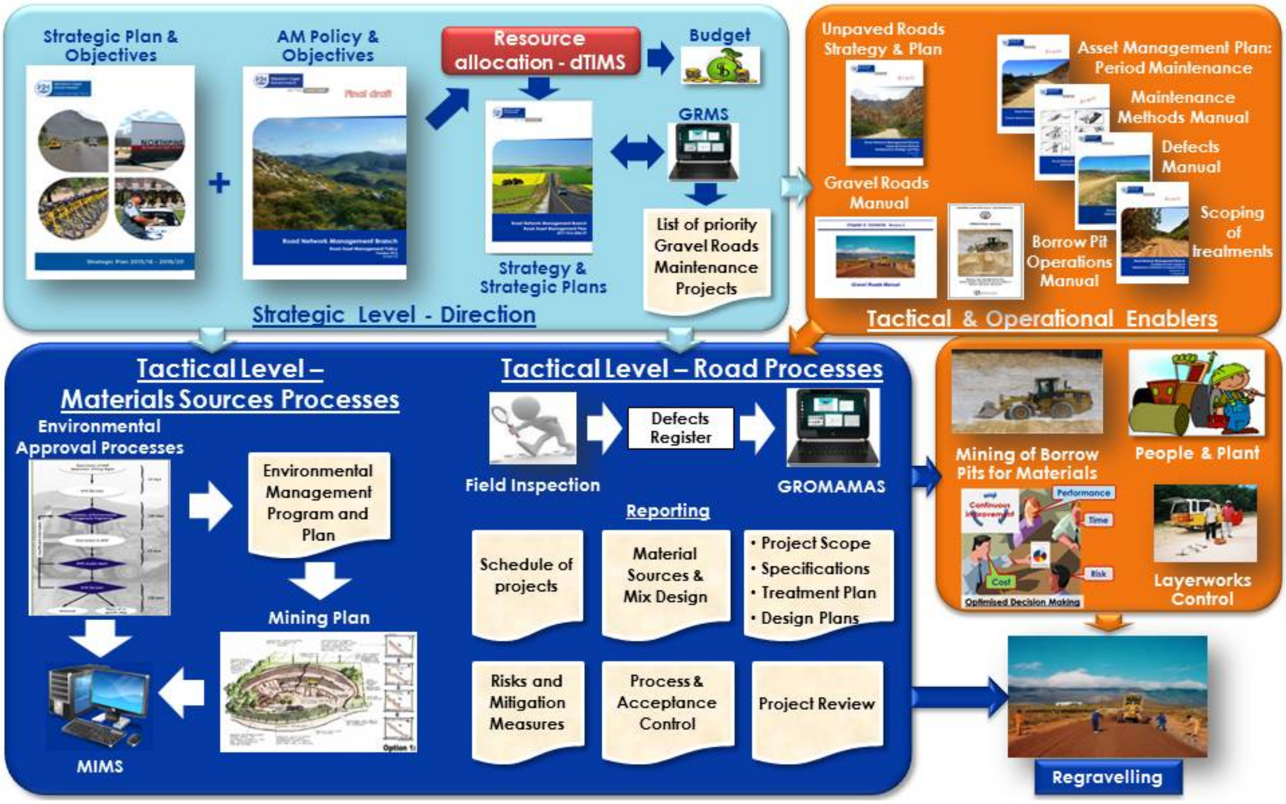


Figure 2: The unpaved road maintenance system

The development of the Strategy for Maintaining Unpaved Roads in the Western Cape (Western Cape Government, 2017a) is a critical component of the Unpaved Road Maintenance System that enables the connection of tactical planning and operational maintenance activities with the strategic objectives and encourages discussion on cost, performance and risk to spur on improvements that should lead to better network performance. The unpaved roads strategy describes the vision: *'A network that complies with the targets set for mobility, accessibility and safety, as described by the desired level of service. The Gravel Road Maintenance Management System will be used to support all aspects of the maintenance task'*.

The strategic level of the Unpaved Road Maintenance System provides direction through the level of service (LOS) for each link of the network, a constrained, optimised budget and candidate periodic maintenance projects based on the *'Selection of appropriate periodic maintenance activities'* (Provincial Administration of the Western Cape, 2007) that describes the principles for decision-making for maintenance treatments. LOS for each link of the network were primarily determined using five traffic classes as shown in Table 1.

Table 1: Traffic classes used in determining level of service

Traffic class	1	2	3	4	5
Traffic range [Annual Average Daily Traffic - AADT]	AADT ≥200	150≤AADT<200	100≤AADT<150	50≤AADT<100	AADT ≤50
Network [km]	1 240	684	1 395	2 254,8	4 791

Other factors that are used to modify the LOS are agricultural and tourism activity. The maximum of these two factors adjusts the LOS upwards by one LOS class. Future developments will include social services, such as schools and mobile clinics as additional factors that modify the LOS upwards. The LOS is associated with appropriate work activities and treatments required under a constrained budget. Preliminary LOS (Table 2) are similar to recommendations in TRH 20 (Committee of State Road Authorities, 1990). The associated work activities and treatments are listed in Table 3.

Table 2: Preliminary levels of service for unpaved roads

Level of service	**Mobility**			**Accessibility**[1]	**Safety rating in terms of dustiness**[2]	**Proportion of the unpaved network [km]**
	Intervention Roughness [p90 IRI]	**Minimum Speed [km/h]**	**Target**[3] **Average Roughness [IRI]**			
High	7,5	80	4	99,5%: In service for ≥363 days pa	≤3	2 516,7
Medium	10	60	5	99%: In service for ≥361,5 days pa	≤4	1 760,5
Low	13	40	6	99%: In service for ≥361,5 days pa	≤4	3 013,2
Very low	15	20	6	99%: In service for ≥361,5 days pa	≤5	3 090,4

Notes:
1. Capacity of a normal car to negotiate the roads without losing traction
2. Visual assessment rating based on TMH 9 (Committee of Transport Officials, 2016)
3. Target currently an estimated value to be adjusted based on results from monitoring of experiments

Table 3: Treatments and activities for planned maintenance according to level of service

Level of service	**Treatments**	**Activities**
High and Medium	Reshape Rework Regravel based on priority (economics, social factors and risk)	Blading maintenance Drainage work Spot regravel
Low and Very Low	Reshape	Blading maintenance Drainage work Spot regravel

There are several tactical and operational enablers that connect to the strategic level and support delivery of maintenance. These enabling documents include the '*Unpaved roads Strategy and Plan'* (Western Cape Government, 2017a), the '*Gravel Roads Manual*' (Western Cape Provincial Administration, 2006a), the '*Maintenance Methods Manual'* (to be compiled), the '*Asset Management Plan for Periodic Maintenance'* (Western Cape Government, 2017b), '*Gravel Roads Maintenance - Defects Assessment Manual*' (Western Cape Government, 2016), *'Scoping of Treatments'* (Western Cape Government, 2017c) and '*Operations Manual*' for borrow pits (Western Cape Provincial Administration, 2006b).

The Tactical Level – Material Sources Processes, delivers plans for gravel sources. The Tactical Level – Road Processes, determines the scope of work, a specification for maintenance activities, a cost estimate and an evaluation of risk.

The scarcity of materials and its effect on the availability of in-specification materials (Western Cape Provincial Administration, 2008) and blading maintenance with respect to the different levels of service is an ongoing challenge to achieving the best performance. The strategy provides guidance on the trade-offs involved in the use of out-of-specification materials and a risk assessment (Western Cape Government, 2017a).

Projects are scheduled at the tactical phase, as well as determining the scope and standard for treatments and activities as well as a cost estimate. This functionality is being provided in the Gravel Road Maintenance Management System (GROMAMAS) and will enable the District Roads Engineer to control the scope of work, cost of each project, its scheduling and progress. The operations phase depends on process and acceptance control functionality provided in GROMAMAS. Project review reports during the time period under consideration enables the discussion on cost and performance against project objectives in terms of progress and quality of the final product. Associated risks can be evaluated and mitigation measures implemented.

3 DEMAND-SUPPLY MODEL

A demand-supply model was developed that models the current demand for gravel using the gravel loss model of Paige-Green (Committee of Transport Officials, 2016), the required supply of gravel and the regravel teams to construct the layer of wearing course. The model includes the variables of traffic, Weinert N-value (a measure of macro-climate), gradation and plasticity. The model parameters are regravelling thickness, the average thickness of the gravel on the network, and the number of regravel teams. Outputs are the quantity of gravel required, the time to reach a steady state thickness of gravel on the network, and the number of regravel teams required to sustain the steady state thickness of gravel. The model simulates the ongoing process of gravel loss for each road section. This process continues until the gravel thickness reaches a trigger thickness, i.e. a thickness where the road should be regravelled in order to facilitate blading maintaince. The model prioritises roads for regravel by sorting them firstly by LOS, and then by gravel loss, and lastly according to the thickness of gravel left on the road. A road can be regravelled after it has been triggered, but only if there are sufficient resources (regravel teams) available. When resources are depleted, i.e. the total production by a limited number of teams is consumed, the model ends the regravelling activities for that year and new regravelling projects will only commence the following year.

With the current limited number of regravel teams and very little gravel left on the network, about 580 km of road that have very high gravel loss consume most of the resources, requiring frequent regravelling, and preventing roads with a lower gravel loss from being regravelled. Consequently, a large part of the network cannot be regravelled with the limited number of available regravel teams.

Figure 6 shows the model results for an average target network gravel thickness of 60 mm, a regravel trigger of 40 mm, a 150 mm regravel layer, and a 25% reduction in gravel loss for high quality construction and good quality gravel wearing course. The number of regravel teams is constrained to 10 and the quantity of material required is determined by the rate of production of the 10 teams.

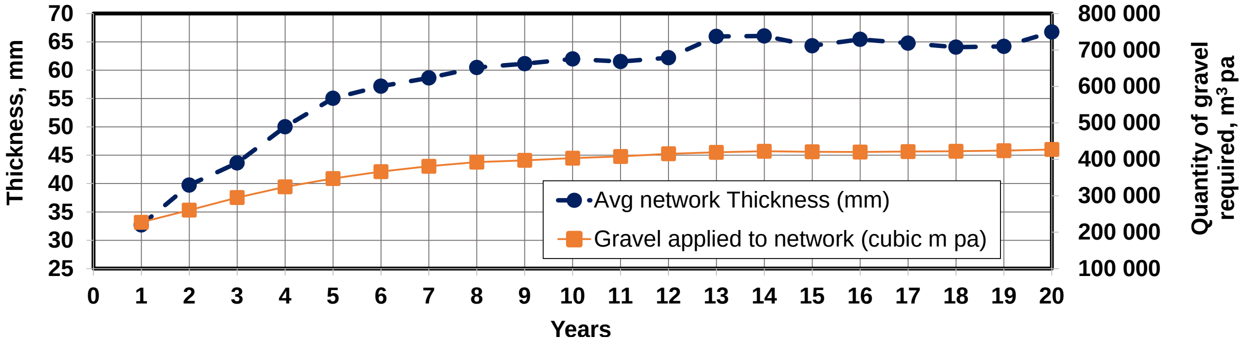


Figure 3: Average thickness of gravel on the network and quantity of gravel required

Various scenarios were tested in the spreadsheet and the results are shown in Figure 7. The scenarios covered the current situation, reduced gravel loss (Van Zyl, et al., 2003a) (Van Zyl, et al., 2003b) and upgrading of unpaved roads. Two thicknesses of gravel wearing course were modelled, i.e., 100 mm and 150 mm, as well as the impact of upgrading to paved standards for 120 km and 240 km of unpaved road that have high traffic volumes and high gravel loss. The scenario where a thicker layer of gravel wearing coarse (150 mm) is applied enables more of the roads with a high rate of gravel loss to retain sufficient gravel for a number of years, allowing more km of road with a lower demand for gravel to be regravelled in the years that follow. When a thin 100 mm layer of gravel is applied, it initially results in gravel being spread over more roads, but the demand for regravel from the high gravel loss roads eliminates regravelling on the lower gravel loss roads in the years that follow. By applying a 150 mm layer of gravel, the demand for regravel from the high gravel loss roads is delayed, and this enables a steady state target thickness on the network to be reached sooner.

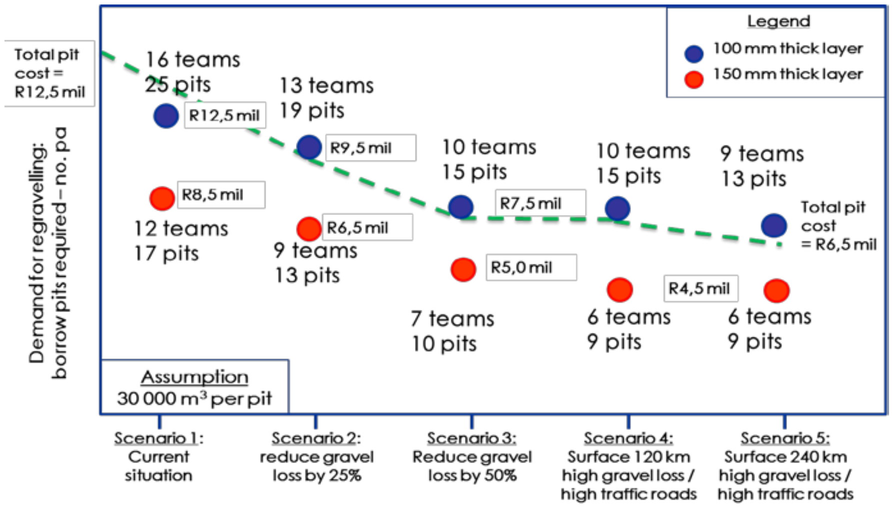


Figure 4: Scenarios for determining the effect of different options to achieve a sustainable network

Future development will be to customise the Branch’s resource optimisation system (Deighton Total Infrastructure Management System - dTIMS®) to include the LOS and demand-supply model in order to optimise the supply side (teams, staff and construction plant) of delivering periodic maintenance under a constrained budget.

4 REVIVAL AND REDEVELOPMENT OF MANAGEMENT INFORMATION SYSTEMS

The GMS was revived and rebranded as the Gravel Roads Maintenance Management System (GROMAMAS) (Figure 8) and supports the business processes associated with maintenance of the unpaved road network. Processes were revised and improved modules are being implemented. The registration of projects is controlled by the Branch’s Project Management System and scheduling is done in the Scheduling Module. The Project Scoping, Packaging & Programming Module makes use of a defect assessment manual (Western Cape Government, 2016) as the reference for the collection of data on defects. A project is assessed and all the defects are recorded in GROMAMAS. Each defect has associated treatments (regravel, reshape, rework), activities (silted culvert, faded signs, etc.), cost and a degree of complexity in order to build a costed bill of quantities that is associated with the gravel sources selected from MIMS. A new, universal risk module will assist risk assessment and mitigation of risks during regravelling work.

A tool to assist with determining the number of trucks required for the haul distance in order to balance the supply of gravel with the production of the regravel team will be provided in GROMAMAS. A review of current practice at the DMs and past research (Van Zyl, 2011), (Burger, et al., 2007) for the optimisation of blading maintenance was completed from which a user requirements specification was compiled. Functional and technical designs will be prepared for the creation of the Blading Optimisation Module of GROMAMAS. The output will be optimised blading programmes.

The impact of environmental and mining regulations on the legalisation, mining and rehabilitation of gravel sources led to new requirements for functionality in the Materials Information Management System (MIMS) to facilitate compliance and effective management of gravel sources. Figure 8 shows the functionality and process flow of MIMS and how the system provides information to the Materials Selection and Design Module in GROMAMAS to plan effective gravel utilisation.

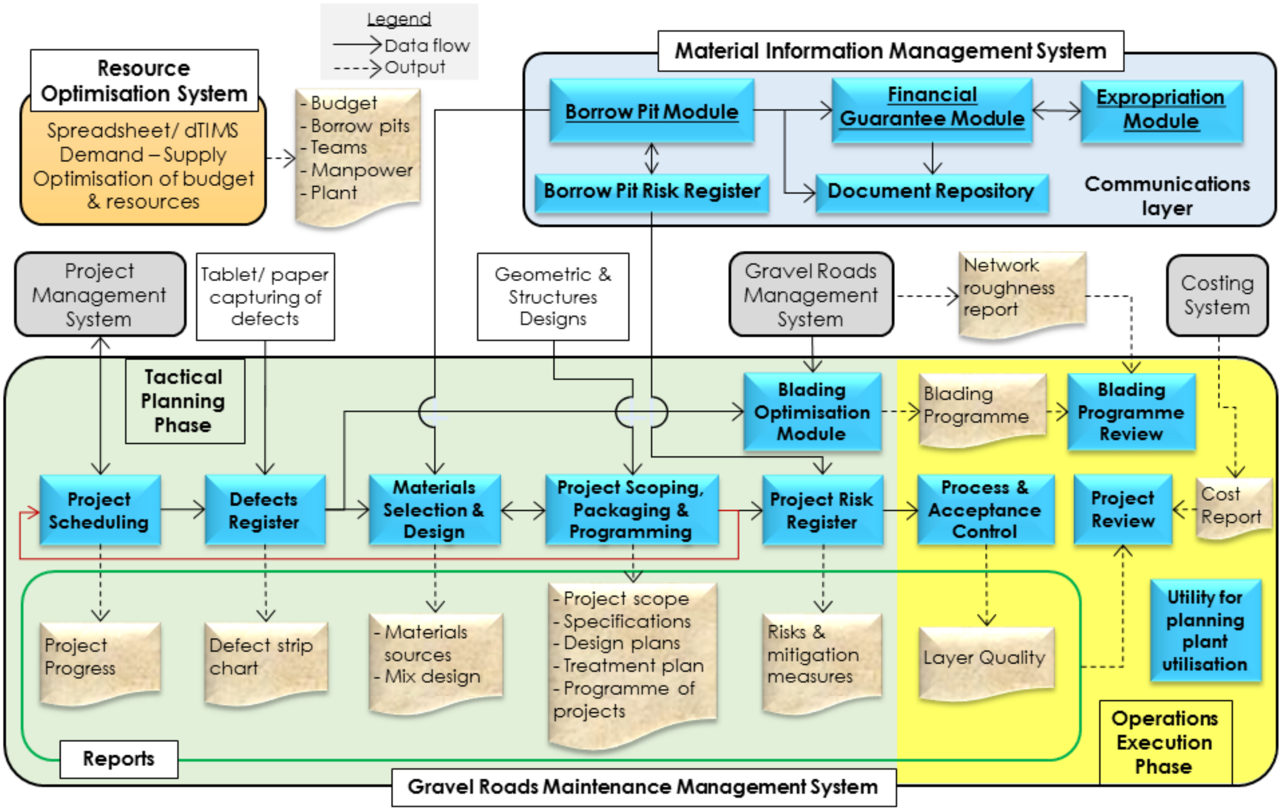


Figure 5: GROMAMAS and MIMS modules and processes

The new business processes supporting the implementation of the mining regulations were documented, and, once incorporated in MIMS, will enable all the processes involved in legalisation of materials sources, including environmental, water, heritage, mining, and financial guarantee approvals to be monitored; as well as approval of the rehabilitation of gravel sources and the return of the financial guarantee. The new, universal risk module will assist risk assessment and mitigation of risks during the investigation, mining and closure stages of a borrow pit.

5 IMPROVING TECHNIQUES AND TECHNOLOGIES

There is an ongoing effort to improve the techniques and technologies of treatments and activities and the monitoring and control of quality. Monitoring sections have been set up across all DMs with the objectives of improving maintenance techniques and developing calibrated HDM-4 deterioration models (Van Zyl, et al., 2007). Data from the monitoring sections and network data will assist in determining appropriate gravel specifications.

5.1 Blading optimisation

The current best practice applied in two Districts (Van Zyl, 2011) and TRH 20 (Committee of Transport Officials, 2016) as summarised in Figure 10, require an initial estimate of the blading frequency to maintain the target road roughness set for a selected LOS. Investigations into different performance models and the ability to calibrate the local conditions and blading type resulted in the selection of the HDM-4 version 2) (World

Road Association, n.d.) models for this purpose. The “steady state” of roughness, is a function of traffic, material properties, climate, road geometry, blading type and frequency. Testing the recommended default values of HDM-4 did not provide acceptable answers, highlighting the need to calibrate the models for the local conditions.

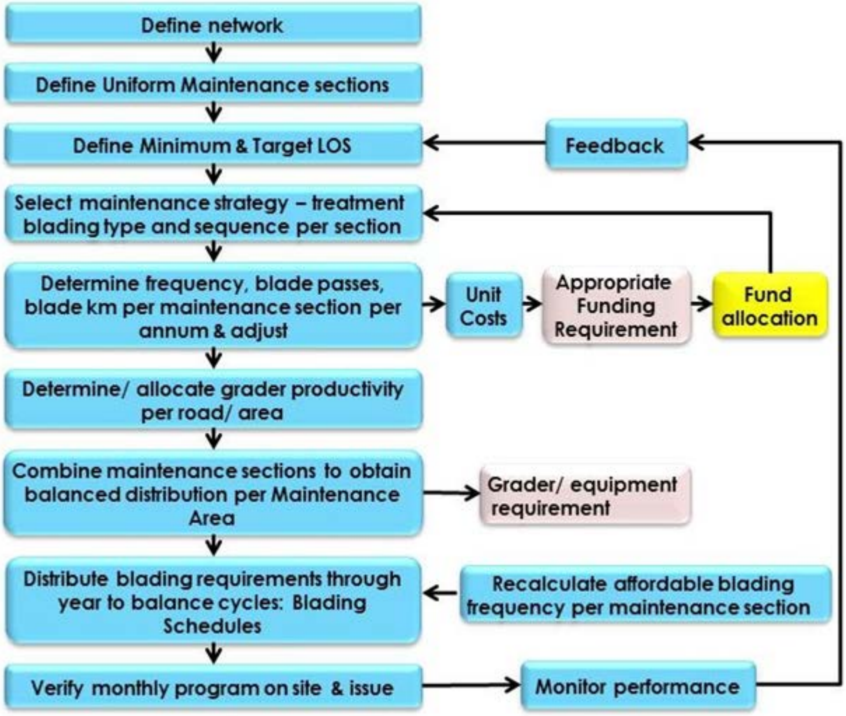
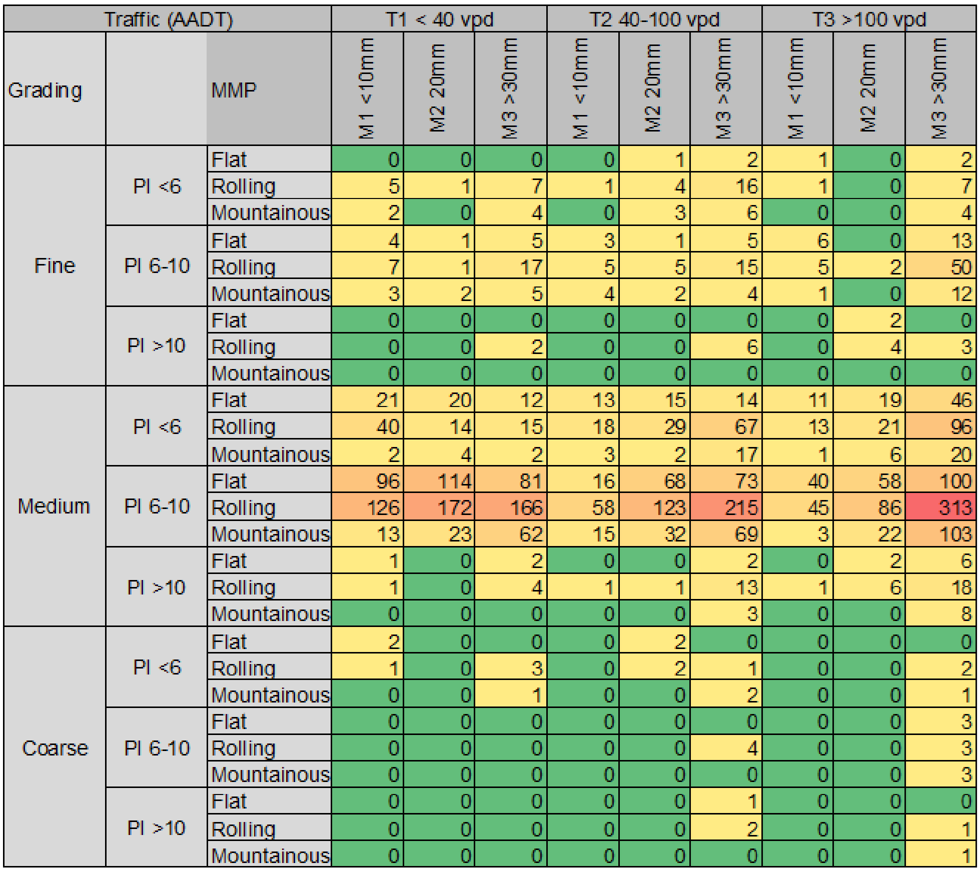


Figure 6. Blading optimisation process



Traffic (AADT)			T1 < 40 vpd			T2 40-100 vpd			T3 >100 vpd		
Grading		MMP	M1 <10mm	M2 20mm	M3 >30mm	M1 <10mm	M2 20mm	M3 >30mm	M1 <10mm	M2 20mm	M3 >30mm
Fine	PI <6	Flat	0	0	0	0	1	2	1	0	2
		Rolling	5	1	7	1	4	16	1	0	7
		Mountainous	2	0	4	0	3	6	0	0	4
	PI 6-10	Flat	4	1	5	3	1	5	6	0	13
		Rolling	7	1	17	5	5	15	5	2	50
		Mountainous	3	2	5	4	2	4	1	0	12
	PI >10	Flat	0	0	0	0	0	0	0	2	0
		Rolling	0	0	2	0	0	6	0	4	3
		Mountainous	0	0	0	0	0	0	0	0	0
Medium	PI <6	Flat	21	20	12	13	15	14	11	19	46
		Rolling	40	14	15	18	29	67	13	21	96
		Mountainous	2	4	2	3	2	17	1	6	20
	PI 6-10	Flat	96	114	81	16	68	73	40	58	100
		Rolling	126	172	166	58	123	215	45	86	313
		Mountainous	13	23	62	15	32	69	3	22	103
	PI >10	Flat	1	0	2	0	0	2	0	2	6
		Rolling	1	0	4	1	1	13	1	6	18
		Mountainous	0	0	0	0	0	3	0	0	8
Coarse	PI <6	Flat	2	0	0	0	2	0	0	0	0
		Rolling	1	0	3	0	2	1	0	0	2
		Mountainous	0	0	1	0	0	2	0	0	1
	PI 6-10	Flat	0	0	0	0	0	0	0	0	3
		Rolling	0	0	0	0	0	4	0	0	3
		Mountainous	0	0	0	0	0	0	0	0	3
	PI >10	Flat	0	0	0	0	0	1	0	0	0
		Rolling	0	0	0	0	0	2	0	0	1
		Mountainous	0	0	0	0	0	0	0	0	1

Figure 7. Matrix for steady state roughness calibration

The availability of data, per 5 km road segment, within the Gravel Road Management System (GRMS) facilitated a process to fill the cells within the possible matrix (Figure 11) and selection of 67 appropriate monitoring sections.

Due to the high variability in climate and material properties throughout the Western Cape, different blading methods are applied: light, dry blading using motorised graders or towed graders; heavy, wet blading using normal blades or serrated blades; tyre dragging and sand cushioning. The applicability and cost-effectiveness of the different methods, currently applied under different conditions, are not defined well enough to establish optimum maintenance strategies. In addition to this, local experience and elsewhere in the world (Skorseth & Selim, 2000) indicates that the effect of other maintenance methods should be investigated. Therefore, monitor-ing sections were established to measure limitations and quantify the effects on road roughness and gravel loss using various maintenance methods and strategies, including crushing of oversize material, rolling after blading, tyre dragging, sea water treatment and serrated blade grading.

Results from these monitoring sections, complemented by previous studies regarding the effects of construction quality (Van Zyl, et al., 2003a) and various additives (Van Zyl, et al., 2003b) will assist in reducing maintenance costs, while adhering to the selected LOS, and help to establish optimum blading and maintenance strategies for different situations on the unpaved road network.

5.2 Crushing of material

With reference to the “Poor and Very Poor” proportion of the unpaved road network as displayed in Figure 12, the predominant defect, assessed according to TMH 9 (Committee of Transport Officials, 2016), is oversized aggregate in the wearing course (stoniness fixed), as shown in Figure 12 and Figure 13. This situation not only results in poor roughness, but also requires a different blading method when compared with a finer wearing course material. Two roads were selected where road sections were constructed using material from the same borrow pits to compare the performance of the material processed on the road (Figure 13) and the same material crushed to minus 26 mm before it was processed on the road. Monitoring these sections over a period of four months showed that the crushed material sections could be maintained at an International Roughness Index (IRI) of 1 less than the uncrushed sections with far less effort, i.e. 5 light blades versus ten heavy blades over the width of the road and at least one less blading per annum. At an Average Annual Daily Traffic (AADT) of 150, the savings for the Road Authority amounts to R 10 000 per km per annum and the Vehicle Operating

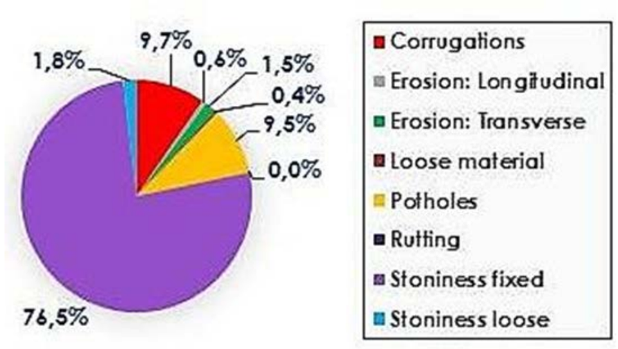


Figure 8. Predominant defects on roads in Poor and Very Poor condition

Figure 9. Oversize aggregate reflected by the 'Stoniness fixed' defect

Cost (VOC) savings are R 15 000 per annum, giving a total of R25 000 per km per annum. In simple terms, without taking the increase in VOC into account and discounting to Net Present Value (NPV), this means that for a regravelling frequency of ten years, the total savings would be R 250 000 per km. The unit cost of crushing the material, whether using a mobile crusher in the borrow pit or an in-line crusher could be offset against the savings to determine the viability of crushing.

5.3 Rolling after blading

Blade & Roll systems are used in several countries with good results highlighted by different organisations. However, no results could be obtained to quantify the cost-effectiveness of the system. Based on a number of experiences in the Western Cape using pneumatic tyred rollers (PTR) for final compaction after regravelling, an experiment was designed to simulate the "blade & roll" system by using a six ton PTR after the wet blading action. Three sections were selected on the same road, but with different material properties. Half of each section was rolled after the wet blading activity and the performance in terms of roughness deterioration and gravel loss was measured over periods of 54 and 65 days. The intention is to increase the mass of the roller during the follow-up process to quantify the effect of contact stress. All three sections showed a slower rate of deterioration in roughness on the rolled sections with the average savings in VOC per vehicle pass shown in Figure 14.

Studies by Fossberg (ARRB Transport Research, 2009), indicate economic viability of blading at an average of 6 000 vehicle passes. If this is used as a guideline, then the additional cost of rolling that is economically viable solely from VOC savings, should be less than R 545 per km. However, the effect of rolling on gravel loss measured is significant as shown in Figure 15 and, when taken into account, the benefit of rolling far exceeds the cost thereof.

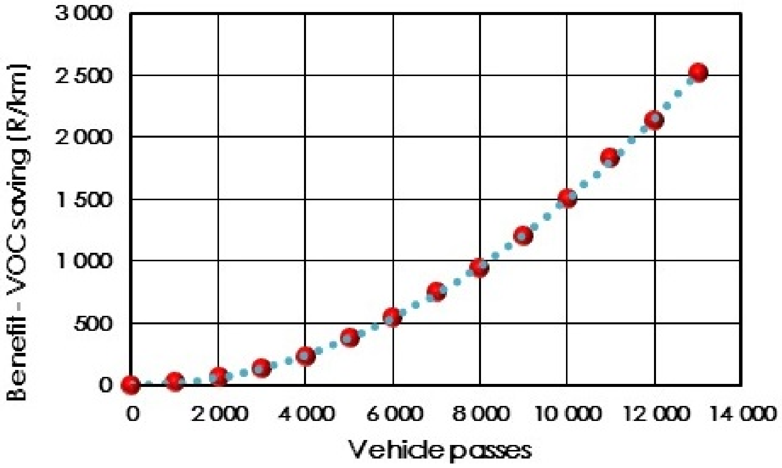


Figure 10 Savings in VOC (Rolled versus No rolling)

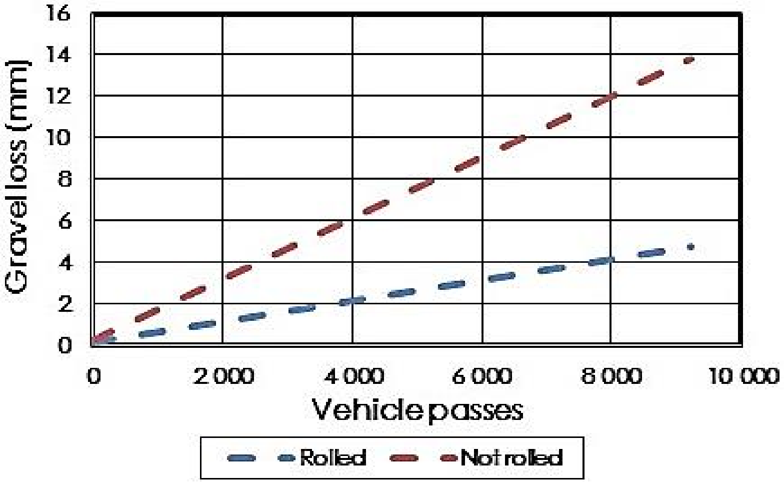


Figure 11 Effect of rolling on gravel loss

During the blading operation 20 mm to 30 mm of material is generated from the existing surface and pick-up from the shoulder, which is then moistened and spread over the width of the road. The logical explanation for the rapid loss on the non-rolled sections is that the material rapidly dries out and gets driven off the road. Even though it is expected that the rate of loss will reduce after the initial 20 mm loss, most of the dust component (minus 0,075mm material) is lost to beyond the road reserve, leaving a material for future maintenance that is difficult to compact.

5.4 Tyre dragging

Good experience in the western parts of the Western Cape and neighbouring countries resulted in the design of several experiments to test the limitations and cost-effectiveness of this treatment. Seven road sections have beenselected and prepared to compare the effect of tyre dragging with light grader blading on different thicknesses and properties of the sand cushion as well as the rate of roughness deterioration, mainly the formation of corrugations, after treatment. Although too early at this stage to report conclusive information, it has been confirmed that the tyre drag, at a cost of less than 40% the cost of light grader blading, is just as effective in the immediate improvement of roughness through removing the loose corrugations. However, as shown in Figure 16, the effect of tyre dragging is minimal when hard corrugations have formed. A motorised grader or towed grader is still required to open up mitre drains, reclaim material from shoulders or side drains and to remove hard corrugations and should be used as part of the total maintenance strategy.

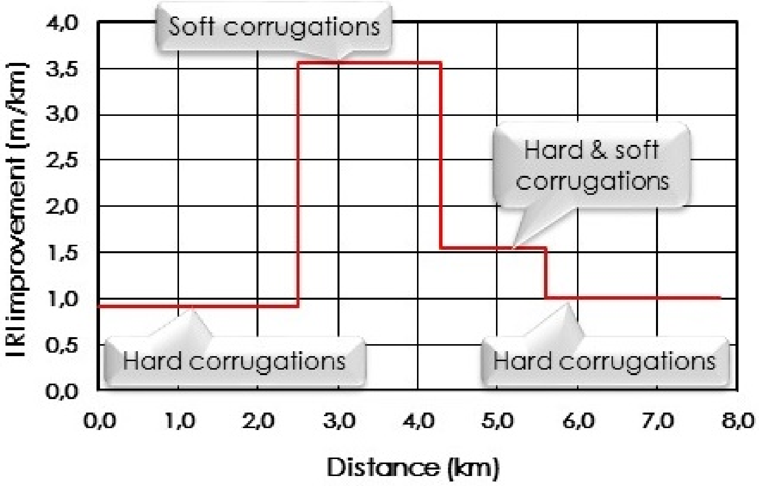


Figure 12 Improvement in roughness due to tyre dragging

5.5 Blading maintenance strategy development

Variability in materials, climatic conditions, topography and traffic volumes require different strategies, i.e. rules for the sequence and frequency of maintenance activities, to maintain a specific LOS at the lowest possible cost.

The first challenge is to select the "package" and sequence of activities appropriate for a set of conditions, e.g., very low traffic, dry area, low cohesion materials and high percentage of oversize. Incorporating sequential activities such as in-line crushing for reworking, different blading types and reshaping into calibrated performance models for this scenario (refer Figure 17) would assist with determining the required frequency of activities to achieve the minimum and target LOS.

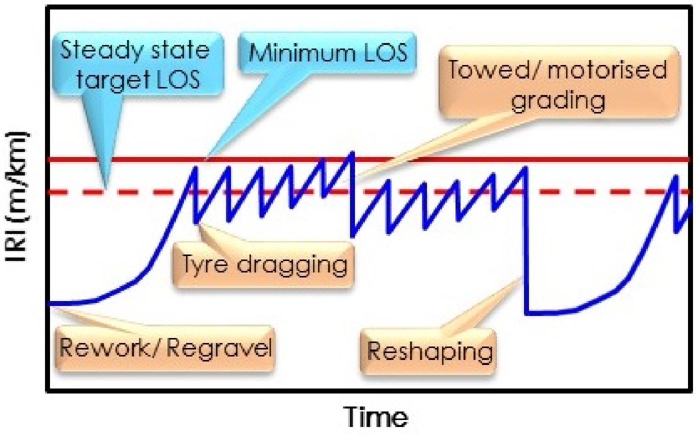


Figure 13. Example of a maintenance strategy

6 FINDINGS AND CONCLUSIONS

The significance of this work lies in the development of a strategy, as part of the Unpaved Road Maintenance System, which enables the connection of tactical planning and operational maintenance activities on the unpaved road network with the strategic objectives and encourages discussion on cost, performance and risk in the time period considered, spurring on improvements in management.

Although monitoring studies are ongoing, sufficient information has been obtained from the current and previous studies, to confirm that the HDM-4 performance models (World Road Association, n.d.) can successfully be adjusted and calibrated to incorporate the quality of construction, specific blading methods as well as other treatments. The study also confirms that the optimum maintenance strategy on a road could consist of different treatments during the maintenance life-cycle and that different strategies are required depending on materials, climate, topography (horizontal and vertical alignment) and traffic.

In conclusion, the approach taken by the Branch to develop and implement a turnaround strategy that includes the refinement of HDM-4 prediction models is expected in the medium term to lead to more effective management, better network performance and outcomes for the community.

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