

A Stochastic Model for the Determination of Rural Road Maintenance Financing Needs

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Abstract - Rural road maintenance in Sub-Saharan Africa is underfunded as the benefits are less tangible than investment in building new roads or funding strategic or national road development. As a result, investment in rural road maintenance is often inefficient, not transparent and motivated by non-needs driven factors. This is having a significant effect on the socio-economic development of rural communities. To ameliorate this, there is a need to present the benefits of rural road maintenance in a concise, transparent and straightforward manner that is meaningful to politicians and senior decision makers.

The research describes work that was carried out to develop a probabilistic tool which is capable of determining the effects of maintenance on road asset condition over time at the network level under budget constraints. The tool consists of Markov based rural road asset deterioration and maintenance effects models. These have been determined as a function of climate and traffic for a variety of assets and geo-environments in the region. The robustness and viability of the tool is demonstrated via data collected from three Sub-Saharan countries.

Keywords—rural roads; maintenance funding; network level; ; asset condition; pobabilistic tool; homogeneous

I. INTRODUCTION

In many Sub-Saharan African (SSA) countries, the maintenance of low volume rural roads (LVRRs) tends to be neglected and as a result the roads are often in a poor state. The lack of investment in LVRR maintenance is due to a number of reasons including political partiality for new construction, inadequate road maintenance budgets, the lack of a suitable means of arguing a strong case for rural road maintenance funding where social benefits are significant, institutional memory loss, inappropriate institutional arrangements and ineffective asset management practices [2]. To identify ways of addressing some of these issues the UK Department for International Development (DFID) is funding a research project through RECAP, titled “Economic Growth through Effective Roads Asset Management project (GEM)”. GEM is encouraging the adoption of sound asset management practices in rural road agencies in SSA and providing capacity building initiatives to help achieve sustainable asset management and thereby measurable improvements in associated socio-economic benefits. Three rural road agencies, Kamuli district in Uganda, Tonkolili district in Sierra Leone and Chongwe district in Zambia are taking part in the current phase of the project.

The project has identified the need for a variety of simple to implement and use tools which can be used by rural road agencies to support their decision-making processes. Several of these are already being trialed and adopted. This paper addresses the development of a network level tool which can support network level rural road agency road management activities.

A. Strategic Road Asset Management

Road maintenance management can be considered as occurring at two separate levels, the network level and the project level (see Fig. 1.).

The former is associated with establishing the budget required to maintain the road network as a whole, to an agreed average condition or associated level of service for a period of time. Network level management is mostly undertaken by the key decision makers in the road agency and is often supported by economic and financial tools. Project level management, on the other hand, is carried out at regional or district level by a suitably qualified and experienced engineer who has the responsibility of overseeing the maintenance of roads in a particular region. The object of this level of management is to determine the specific maintenance requirements of each individual road section within the Engineer's remit. Processes including data collection, setting maintenance standards, treatment selection and prioritisation can be regarded as linking network level and project level management to ensure that the average network condition specified at the network level matches the sum of the condition of the individual road sections maintained at project level. Snaith [3]. proposed a conceptual model of this process as shown in Fig 2. The proposed tool fulfils the task of helping to plan maintenance expenditure (The optimal rolling programme component in Fig. 2).

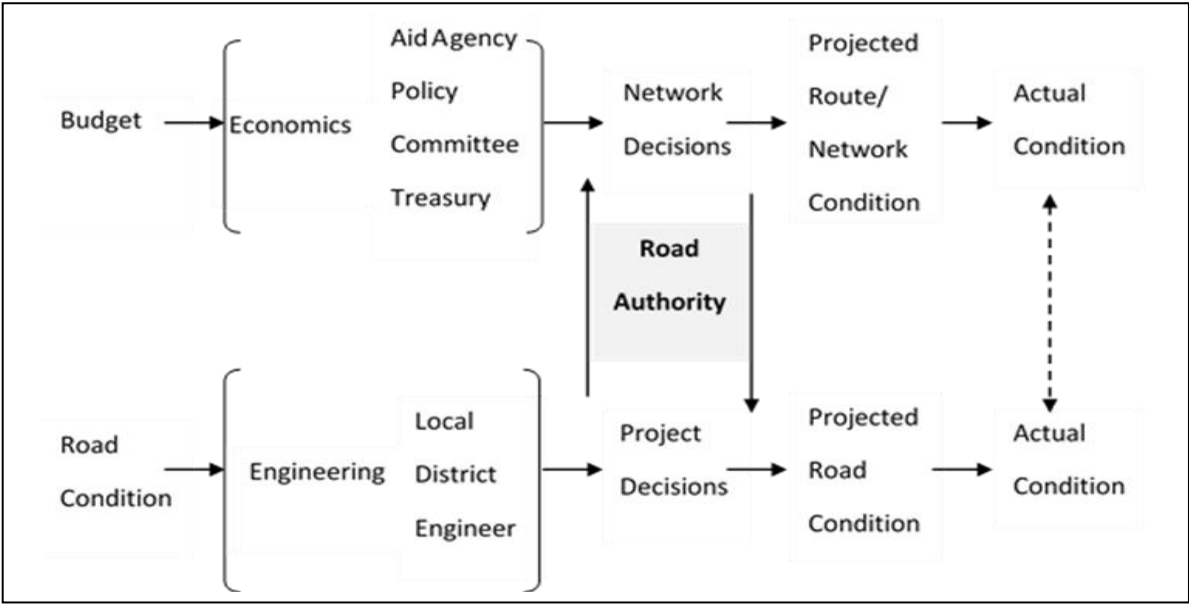


Fig. 1. Network and Project Level Management (After M. S. Snaith)

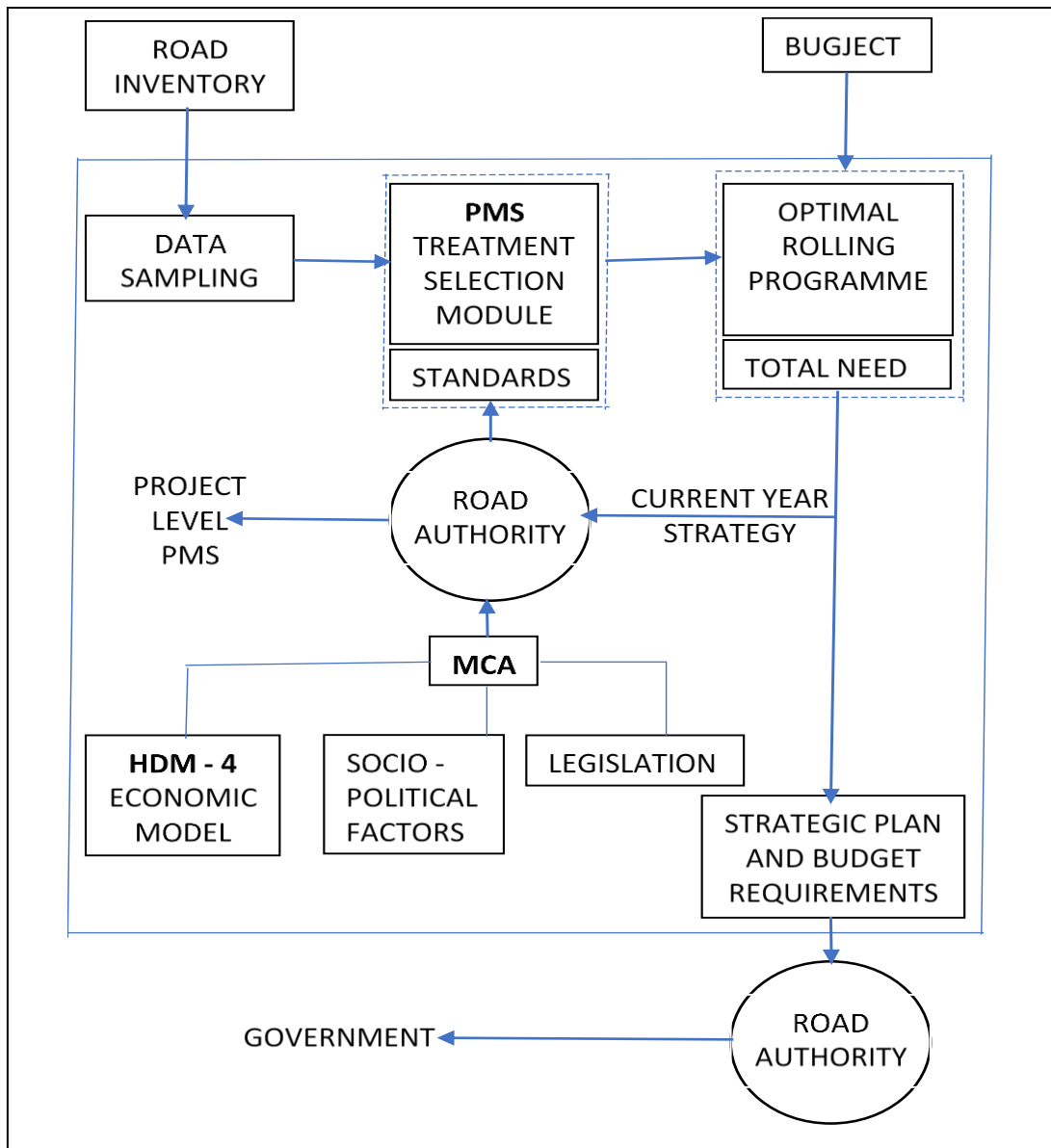


Fig. 2. The Strategic Planning Model (SPM)

There are a variety of computer-based decision support tools which have been developed which could be used to help to develop optimal rolling programmes of maintenance. Perhaps the best known of these to road agencies in SSA is HDM-4, the World Bank's de facto standard for road investment appraisal [4]. Economic benefits in HDM-4 are associated with savings in road use costs (travel time savings, vehicle fuel, maintenance and accident costs). Although HDM-4 is able to consider non-motorized transport it does not directly take into account social benefit and therefore it's use in the LVRR context tends to be within a multi-criteria analysis (MCA).

Its principal disadvantages in the context of rural road management are that it requires considerable data inputs, many of which are impractical to collect, extensive need for model calibrations and sustained training of local staff. Several of these disadvantages have been addressed in a newly released version known as HDMSentry [6]. The World Bank's Road Network Evaluation Tool (RONET) has also been developed by the Bank as a more user friendly and less sophisticated alternative to HDM-4 [5]. Its constituent models are based on simplified HDM-4 relationships, but it requires less data and technical capability to run than HDM-4. In order to address the limitations of HDM-4 and RONET for the analysis of LVRR, the World Bank has developed a simplified

economic evaluation model known as the Roads Economic Decision (RED) Model. RED [7]. is spreadsheet based and capable of relatively sophisticated analyses without requiring input data which may be problematic and costly to collect in the LVRR context [8].

Despite the availability of these tools, it was felt that there was still a need to develop a less sophisticated planning tool, albeit based on a sound theoretical basis, which could be used to argue for funds by presenting network-level benefits in a concise, transparent and straightforward manner that is meaningful to politicians and senior decision makers at local government levels in SSA countries and at the same time enable rural road authorities to plan maintenance expenditure. In particular the tool should:

1. Provide a method of studying the effects of maintenance funding levels on the condition of a rural road network.
2. Predict the total maintenance budget requirement of a typical rural road network in future years and identify future peaks in the requirement for maintenance.
3. Enable studying of the effect of changes in maintenance treatment policies (using approved maintenance standards) on budget requirement and the rural road network condition.
4. Provide an overview of the performance of the rural road network over a number of years.

For reasons of uptake and sustainability it was felt that the tool should satisfy the following practical requirements:

1. Ease of use
2. Should not require extensive calibration
3. Should not require extensive amounts of data, or data that is difficult to collect
4. Be easily understood by those working in rural road authorities and
5. Should not require significant training in its use

II. THE CONCEPTUAL MODEL

Based on the foregoing requirements a theoretical model was developed as illustrated in Fig. 3. The model is based on the principles advocated by the Transport Research Laboratory (TRL) Visual Condition Model for Road Networks (NETCOM) [9]. From Fig. 3, it may be seen that the model includes a number of simulation modules which perform specific tasks including the specification of maintenance budgets and intervention levels, the calculation of maintenance requirements, the simulation of the effects of maintenance treatment on road network condition and modelling road deterioration. These components are discussed below.

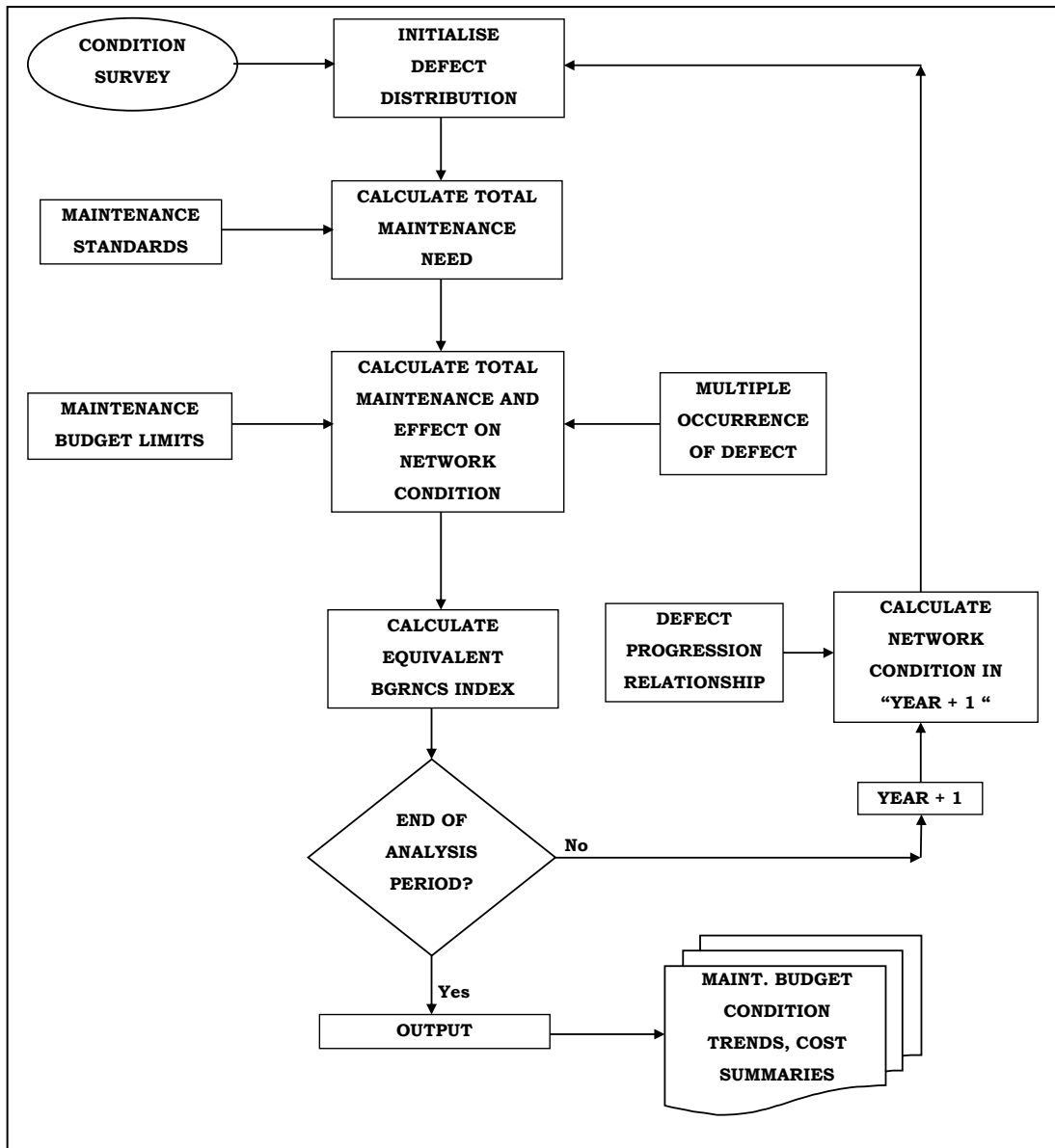


Fig. 3. The theoretical framework of the System (RURALNET)

A. Model Form

Road performance prediction models can be described as deterministic or probabilistic (stochastic). Deterministic models predict condition as precise values using mathematical functions and comprise three groups of models: mechanistic, empirical and mechanistic-empirical. Mechanistic models model the actual performance of the asset with respect to predictors of stresses, strains and deflection. Empirical models are based on observed behaviour in which the dependent variable is related to one or more explanatory variables. Mechanistic-empirical models utilise mechanistic principles to determine the functional form of the model and empirical approaches to combine the functional form with observed data [10] and [11]. Stochastic models are used to predict future condition as a probability function of a range of possible conditions and a common form of stochastic model is based on Markov chains derived from past observations of behaviour [12].

For the purposes of the tool proposed herein it was decided to use stochastic modelling as the literature suggests that road condition, particularly at the network level, is probabilistic in nature, even though variables such as pavement material properties, traffic loading and volume and the impact of the environment, that are well known to be responsible for pavement performance and deterioration are however, not explicitly represented [1]. These concerns are addressed in our tool by dividing the rural road network into homogeneous sub-networks.

1) *Homogeneous rural road network*

So that rural roads exhibiting similar performance can be analysed together, roads which are homogenous with respect to construction type, maintenance standards, environment and traffic use are grouped and analysed together. The overall rural road network is the collection of these homogenous rural road subnetworks.

2) *Road Condition*

The condition of the rural road network at any given point in time is expressed as the percentage of the network in a particular condition state. The rural road network condition **P** at any point in time can be written as:

$$\tilde{P} = \begin{bmatrix} P_{11} & P_{12} & P_{13} & P_{14} \cdots P_{1n} \\ P_{21} & P_{22} & P_{23} & P_{24} \cdots P_{2n} \\ P_{31} & P_{32} & P_{33} & P_{34} \cdots P_{3n} \\ P_{41} & P_{42} & P_{43} & P_{44} \cdots P_{4n} \\ & & \cdot & \\ & & \cdot & \\ & & \cdot & \\ P_{x1} & P_{x2} & P_{x3} & P_{x4} \cdots P_{xn} \end{bmatrix} \tag{1}$$

where P_{xn} is the proportion of the network, with condition x , in severity band n .

For the purposes of the model described here, the measures of road condition are those identified as being appropriate, by the GEM project team, for the assessment of rural road condition. These are shown in Table 1 together with the intervals of condition corresponding to their severity bands. Examples of the probability distribution of severity levels for four of these defects (rut depth, gravel thickness, corrugation and potholes) observed on the rural road network in Tonkolili District are illustrated in Fig. 4.

TABLE I. OBSERVED DEFECT SEVERITY DISTRIBUTIONS ON GEM TONKOLILI DISTRICT NETWORK IN 2017

Severity Band	Rutting		Corrugation		Pot Holes		Gravel Loss	
	Severity (mm)	Proportion (%)	Severity (%)	Proportion (%)	Severity (mm)	Proportion (%)	Severity (mm)	Proportion (%)
1 ^a	0 - 0	16.18	0	13.82	0	2.9	> 125	13.82
2	1 - 19	8.15	1 -19	25.55	1 - 19	12.61	125 -100	25.55
3	20 - 40	41.68	20	8.99	20 - 49	32.27	100- 50	8.99
4	41 - 59	2.1	21 - 39	17.65	50 - 75	6.89	50 - 25	17.65
5	>= 60	31.89	25	33.99	> 75	45.33	< 25	33.99

^a. 1 = Very Good, 2 = Good, 3 = Fair, 4 = Poor and 5 = Very Poor.

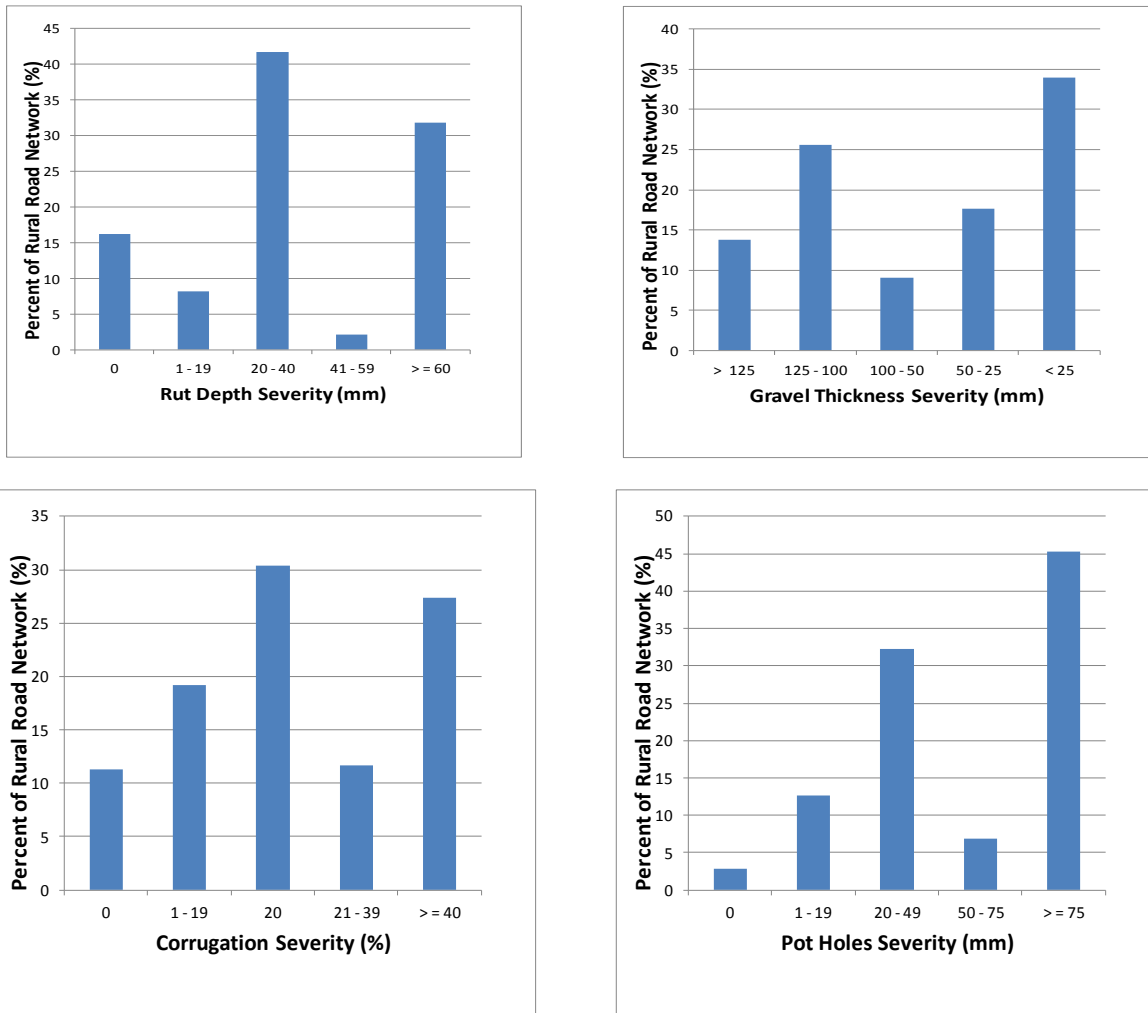


Fig. 4. Typical Defect Severity Distributions.

3) Maintenance Standards

A maintenance standard defines the intervention levels at which treatments are to be applied to a road section. For the tool the maintenance standard consists of the treatment type and the defect(s) it remedies together with the priority order in which the treatments and defects are to be considered. Table II shows the maintenance standards used for the Tonkolli district. The priority orders for both treatments and defects are required when budget constraints do not allow the entire network to be remedied. Treatments are applied in treatment priority order and then in defect priority order until the available budget is exhausted. In Table II, reconstruction is applied when whole carriageway impassability reaches 40% or when whole carriageway erosion is equal to or greater than 60 mm depth, or when the extent of the spread and depth of potholes on whole carriageway is above 60% and are equal to or greater than 75mm respectively, or when whole carriageway corrugation reaches 40% or when rutting is equal to or greater than 60 mm. The maintenance standard also specifies the order in which treatments are to be applied. Table 2 shows that reconstruction will be the first treatment to be applied on the road network followed by rehabilitation, then re-graveling and finally spot improvement. Within each treatment the defect priority defines the order in which defect are to be treated. For example, Table 2 shows that in the part of the road network where we recorded 40% or more impassability will be reconstructed before sections with erosions depths equal to or greater than 60mm.

TABLE II. EXAMPLE SPECIFICATION OF MAINTENANCE STANDARDS FOR GEM ROAD NETWORK

Treatment Type	Treatment Priority	Defect Type	Defect Priority	Intervention Levels
Reconstruction	1	Whole Carriageway Impassability	1	$\geq 40\%$
		WC Erosion (Transverse & Longitudinal)	2	≥ 60 mm
		Pothole	3	≥ 75 mm and $>60\%$ of WC
		WC Corrugation	4	$\geq 40\%$
		Rutting	5	≥ 60 mm (i.e. condition band 5)
Rehabilitation	2	WC Erosion (Transverse & Longitudinal)	1	40 mm - 60 mm
		Pothole	2	>50 mm and $>50\%$ WC
		WC Corrugation	3	21% - 39%
		Rutting	4	41 mm - 59 mm
		Gravel Loss	5	50 mm - 25 mm
Re-graveling	3	Gravel Loss	1	≤ 25 m
		Pothole	2	>20 mm and $>40\%$ WC
		WC Corrugation	3	20%
		Rutting	4	20 mm - 40 mm
Spot Improvement	4	Pot hole	1	$=19$ mm and $< 40\%$ WC
		WC Corrugation	2	$\leq 20\%$
		Rutting	3	1% - 19%

4) Calculating the Budget Required for a Specified Maintenance Standard

a) Single Defect Rectification

The percentage of the conceptual rural road network requiring maintenance is obtained from the sum of road sections with defect severity levels which exceed the intervention levels specified in the corresponding maintenance standard. For example, from Table 2 the proportion of the network requiring reconstruction is given by the proportion with (a) whole carriage way impassability greater than 40%; or (b) corrugation greater than 40%; or (c) transverse and longitudinal erosion deeper than 60mm; or (d) potholes deeper than 75mm; or (e) rutting depths above 60mm. These items are calculated from the defect distributions such as those given in Table 1 and illustrated in Fig. 3. This process is repeated for all treatment types given in the maintenance standard and the values aggregated.

When a maintenance treatment is applied, it is assumed to eliminate the causative defect. For example, if 31.89% of the network is reconstructed to eliminate the rutting of severity greater or equal to 60 mm (see Table 1), this would alter the defect severity distributions by increasing the percentage of the network in severity band 1 by 31.89% and decreasing that in severity band 5 to zero. However, the percentage of the road network that can be reconstructed will be limited by the maintenance budget specified for reconstruction.

b) Multiple Occurrence of Defects

The procedure described above assumes that all defects occur independently of each other. For example it assumes road sections with rutting have no other defects. In practice, however maintenance applied to eliminate one type of defect will treat other defects occurring on the same road section. For example, according to the maintenance standard given in Table 2 reconstruction applied to road sections with rutting greater than 60mm will eliminate all other defects previously present on these same road sections. In order to take account of this the joint occurrence of more than one defect on the same section of road is specified. Table 3, illustrates an example of the joint occurrence of defects. The table shows the percentage of a road network with a given primary defects having other secondary defects. For example, Table 3 shows that out of the proportion of the road network which was rutting, 40% also has corrugations, 15% has potholes and 5% has gravel loss. The two-dimensional table is a simplified form of an

otherwise complex multi-dimensional relationship. Many parts of a road network will have more than two types of defect occurring at the same time, and consequently the sum of joint occurrences for a primary defect in Table 3 may exceed 100%.

The multi occurrence of defects shown in Table 3 is used to compute the total percentage of the conceptual network in need of maintenance. As each primary defect is treated, the severity distributions of secondary defects are also affected. For example, if 31.89% of the rural road network with rutting greater than 60mm is reconstructed, this would imply that approximately 12.75% of this, which also had corrugation, will be treated at the same time (i.e. 40% of 31.89%). In this case the distribution of corrugation severities is adjusted so that the percentage of the network with no corrugation (i.e. severity band 1) is increased by 12.75%. The method of adjusting the severity distributions of secondary defects assumes that all severity levels are affected by the applied treatment with the exception of those which would trigger higher order treatments.

TABLE III. EXTENT OF MULTIPLE DEFECTS ON SECTIONS OF THE ROAD NETWORK

Primary Defect	Secondary Defects			
	WT Rutting	WC Corrugation	Pot Hole	Gravel Loss
Rutting	----	40%	15%	5%
WC Corrugation	30%	----	20%	17%
Pot Hole	40%	28%	----	30%
Gravel Loss	20%	15%	25%	----

The approach is carried in a step by step manner. In the first step the treatment assigned the highest priority in Table 2, is applied to the first primary defect, thereafter the distributions of secondary defects which occur on the same road sections with the primary defects according to the multiple occurrences are recalculated. This is repeated for all defects which trigger the treatment, and then for all maintenance treatments in the specified treatment order. When this is completed, the resulting distributions of the defect severities represent the change in condition of the road network due to annual maintenance. In addition, the percentage of the network computed to have been treated gives the total maintenance requirements for the network based on the specified maintenance standard.

c) Maintenance Budget Limits

The preceding section describes how defective parts of the GEM rural road networks can be treated with an unconfined budget. In practice however, budgets are limited and so the tool assigns maintenance firstly by treatment priority and then by defect priority until the available budget is consumed. Budgets can be assigned globally or by treatment type. Maintenance treatments are applied until the relevant budget is exhausted. If the total budget requirement is less than the percentage requiring treatment under the given budget, there will be a short fall under the given budget and part of the road network will remain untreated. Table 4, provides an example of the latter approach using simulated data to reflect the expenditure profiles from Tonkolili district, showing the proportion of the annual maintenance budget allocated to each treatment type together with the unit cost of treatment.

TABLE IV. SPECIFICATION OF ANNUAL MAINTENANCE BUDGET LIMITS

Treatment Type	Proportion of Maintenance Budget (%)	Unit Maintenance Cost (GBP1000/Km)	Average Scheme Length (Lane Km)
Reconstruct	20	44	16.8
Rehabilitation	29	17	31.2
Re-graveling	33	5	52.0
Sport Re-graveling	18	1	80.5

The tool allows sensitivity analyses to be performed so that the effect of budget allocations on network condition can be scrutinised.

d) Pavement Defect Progression

The final step in the modelling process predicts the annual changes in the distribution of road network condition using observed distributions of deterioration in defect severities (see Fig.3). Table 5, known as a transition matrix, illustrates a typical specification of the annualized change in rutting severity for Tonkolili district. The first line in the table shows the observed progression in rut depth severities. For example, 93% of the road network with no signs of rutting in a given year will continue to show no rutting in the following year, but 4% of the network with no rutting will deteriorate to rut depths between 1 - 19 mm and 2% will deteriorate to rut depths between 20 – 40 mm, etc. The second line shows the proportion of the network with between 1 - 19 mm of rut depth in the current year. In the following year, 90% of these will remain within the same band (i.e. 1 – 19mm), but 6% will deteriorate to the next band between 20 – 40 mm, 3% to between 41 – 59 mm and so on. For the purposes of the GME project the distribution of defect progressions is obtained from observed annual changes in road conditions of the GEM rural road networks in Tonkolili, Kamuli and Chongwe respectively.

TABLE V. DISTRIBUTION OF ANNUAL CHANGES IN RUT DEPTHS

Current Rut Depth (mm)	Rut Depth Severity Range in the following year (mm)					Total
	0	1 - 9	20 - 40	41 - 59	>=60	
0	93%	4%	2%	1%	0%	100%
1 - 19		90%	6%	3%	1%	100%
20 - 40			85%	12%	3%	100%
40 - 59				87%	13%	100%
>=60					100%	100%

The defect progression, or ageing process, shown in Table 5, is performed after maintenance has been applied since it is known that pavements recently maintained can show signs of deterioration soon after treatment. The relationships shown in Table 5, represent a network wide change in condition and may not be applicable to a single length of rural road in isolation. It represents the aggregated effects of traffic loading and the environment. It assumes for example that pavements in the rural road network were designed to take into account current traffic growth rates and current climate. However, if it is expected that significant deviations in the traffic loading or climate will occur, the effects of this can be integrated into the ageing process by judicious modification of the relevant transition matrix.

The progression of the percentage, p_{xny} , of the conceptual network in a severity band n in year y , to another severity bands p_{xmy+1} in the following year, $y+1$, as determined by a particular measure of road condition, x , can be represented as follows:

$$\begin{bmatrix} p_{x1y} & p_{x2y} & p_{x3y} & p_{x4y} & \dots & p_{xny} \end{bmatrix} \begin{bmatrix} d_{x11} & d_{x12} & d_{x13} & d_{x14} & \dots & d_{x1n} \\ d_{x22} & d_{x23} & d_{x24} & & \dots & d_{x2n} \\ & d_{x33} & d_{x34} & & \dots & d_{x3n} \\ & & d_{x44} & & \dots & d_{x4n} \\ & & & & & \dots \\ & & & & & & d_{xnm} \end{bmatrix} = \begin{bmatrix} p_{x1y+1} & p_{x2y+1} & p_{x3y+1} & p_{x4y+1} & \dots & p_{xny+1} \end{bmatrix} \quad (2)$$

where

$$\sum_1^n p_x = 100 \text{ for } y \text{ and } y+1; \sum_1^m d_{xnm} = 1 \quad (3)$$

d_{xnm} is the fraction of the network in severity band n , according to the measure of condition x , that progresses to severity band m after ageing.

e) *Calculation of Defects Indices*

In order to have a common measure of rural road condition, the tool calculates a road condition index, known as the equivalent of the biannual GEM Rural Road Condition Survey (BGRRNCS) defect index that represents the average cost of maintenance required to repair a 1Km length of the road network to an acceptable condition. It also calculates a visual condition index.

BGRRNCS is calculated as follows:

$$BGRRNCS = \frac{\sum_{b=1}^n \sum_{a=1}^m VT_{ab} \times CT_i}{L} \quad (4)$$

Where m is the number of maintenance treatments, and n is the number of homogenous conceptual networks. VT is the amount of maintenance of type a for the conceptual network b . CT is the unit cost of treatment type i and L is the total length of all conceptual networks. A high $BGRRNS$ shows that the rural road network needs a large amount of maintenance and therefore its overall condition is poor.

Visual condition, VC , is calculated as follows:

$$VC = \frac{\sum_{b=1}^n \sum_{x=1}^X p_{xb} \times d_b}{L} \quad (5)$$

where p_{xb} is the percentage of conceptual network b which has “very good”, “good” or “satisfactory” condition measured according to the visual defect x , and d is the length of the homogenous conceptual network j in kilometres. L is the total length of all conceptual networks in the overall rural road network.

III. OUTPUTS

The developed tool provides a number of outputs including:

1. Annual maintenance expenditure by type of treatment,
2. The predicted trend in the rural road network condition,
3. The distribution of defects over the rural network and
4. The summary of any surplus or shortfall in the specified maintenance budget over the analysis period.
5. The condition indices defined above

A. Tool Illustration

The use of the tool is illustrated using data obtained from the gravel road network in the Tonkolili district. Due to several constraint, only a limited length of the respective rural road networks in Tonkolili, Kamuli and Chongwe were approve for the project. In each approved network, homogeneous subnetworks were created. These were considered to be having similar traffic, environmental condition, similar geometric design and mostly same pavement materials. In the case on Tonolili, we have two subnetworks. Tonkolili Gravel Surface (TGS) road network and Tonkolili Earth Surface (TES) road network. Due to lack of enough data, it was decided that we focus on the Tonkolili Gravel Surface (TGS) road network for the time being.. For the purposes of the analysis the initial condition in year 1 was taken to be the condition of the rural road network in 2016 measured according to the defects as given in Table 1. The set of maintenance standards specified in Table 2, was utilized. An aggregated network wide transition probability matrix was determined by comparing, on a section by section basis, the condition of road sections measured in 2016 with those measured in 2017, as shown in fig. 5. Tool outputs were computed over a 20 year period of analysis as a function of varying the amount of funding available for maintenance. Budgets of 100% (unconstrained budget), 50% and 0 % of those required by the system each year to fund all necessary maintenance were adopted. For the 20-years period of analysis, the expenditure streams, as a percentage of the first year, can be derived from the output of the tool.

Aggregated Network Transition Probability Matrix					
	VG	G	F	P	VP
VG	0.40	0.30	0.30	0	0
G	0	0.70	0.30	0	0
F	0	0	0.54	0.28	0.18
P	0	0	0	0.56	0.44
VP	0	0	0	0	1.00

Fig. 5. Typical Defect Severity Distributions

B. Results

Figures 6, 7 and 8, portray the results from the analysis. Figure 6 demonstrates the change in road network condition, whilst Figures 7 and 8 gives the budget levels required to fund all treatments types and asset condition bands as a percentage of first year expenditure.

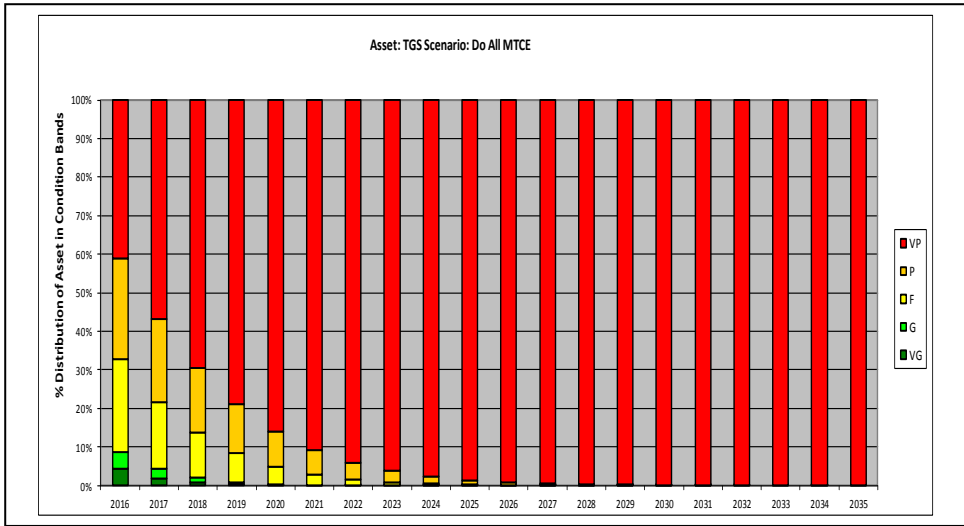


Fig. 6. Tonkolili Gravel Surface (TGS) Network Condition Index

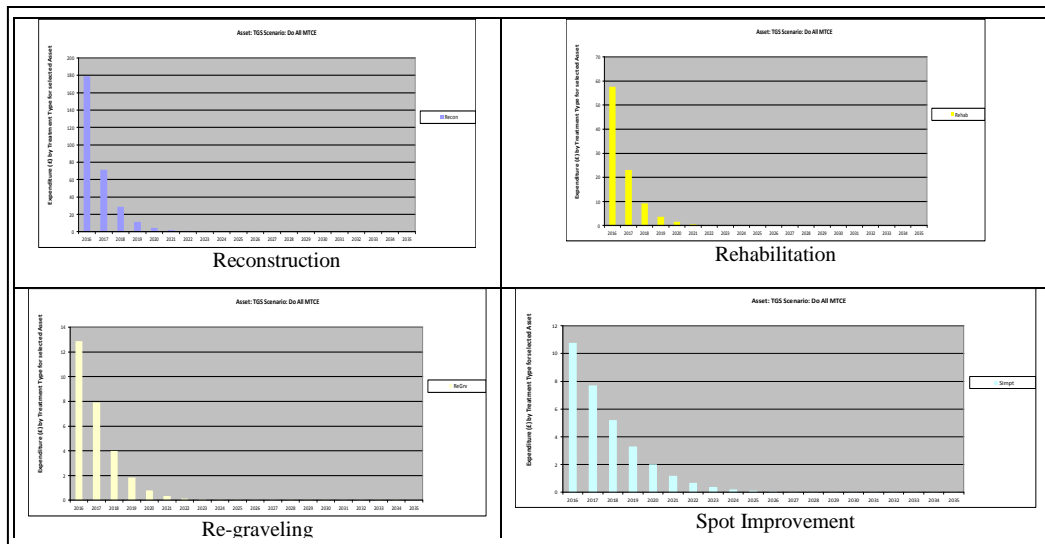
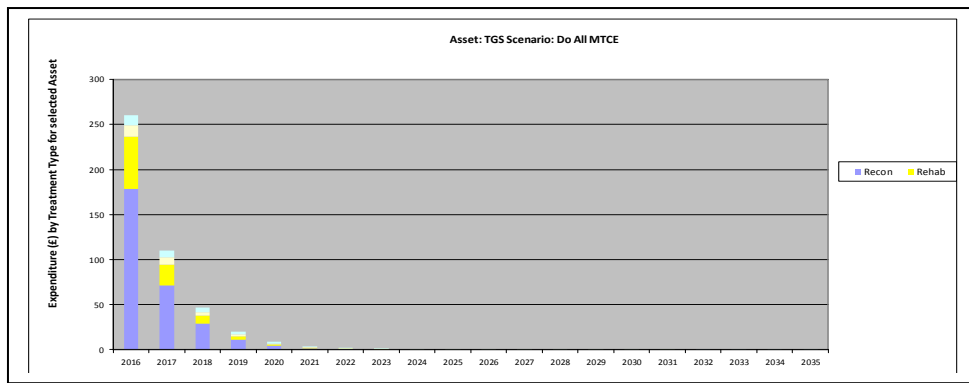


Fig. 7. Expenditure on the various treatment types

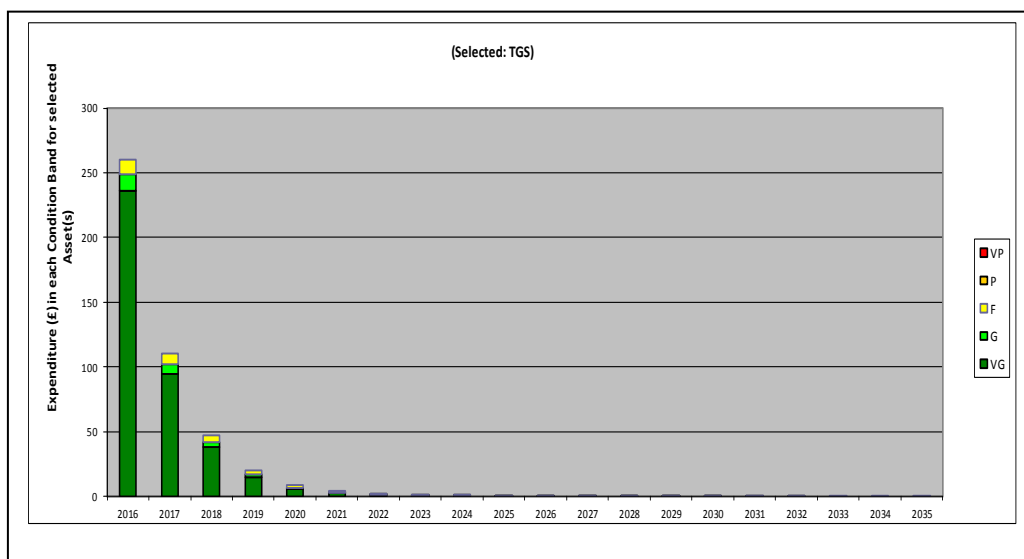


Fig. 8. Expenditure on the various network condition bands as per maintenance standards

C. Analysis

The chosen strategy was designed to priorities major treatment activities such as reconstruction over minor once like spot improvement. The expenditure profiles of the chosen strategy shown in fig. 7 and 8, indicates that more resources is spent mainly on major treatments and predominal n the very good to good sections of the network. These sections gradually increase in propositions within the network as well as their with associated higher unit cost per kilometer. As a result, the fixed annual budget becomes less and less adequate over time to maintain the network. The effect and consequence of this strategy is illustrated in fig. 6.

IV. CONCLUDING DISCUSSION

The framework for a prototype model has been developed for the GEM rural road network which can be used to predict the effects of maintenance funding levels on rural road network condition. The tool is intended to be used by the engineers, development planners and administrators in charge of road maintenance in the three GEM pilot district councils in SSA, as a general purpose tool to argue for funds and to study the consequences of a wide range of maintenance scenarios. It's designed to be a user-friendly model, enabled to be used with a wide range of rural road networks with different characteristics to be analysed. The tool incorporates a versatile mechanism for modelling a variety of defect progressions which can be easily calibrated to match observed network performance. The ability of the model to predict future condition accurately will be enhanced with greater access to more data from the ongoing GEM project in SSA. Such data will enable the development of improved defect progression relationships which take into account changing environmental and traffic loading characteristics over time.

ACKNOWLEDGMENTS

The financial support of DFID through ReCAP is gratefully acknowledged. Valuable insight and data has been provided by our GEM project colleagues and partners supervised by the professional GEM Advisory team leads (GAT). The Department of Civil Engineering at the University of Birmingham is thanked for its financial and practical support.

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