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# Development of optimal road maintenance fund allocation framework

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## ACRONYMS AND ABBREVIATIONS

| | | |
|---|---|---|
| AADT | – | Annual Average Daily Traffic |
| CAR | – | Community Access Roads |
| ESAL | - | Equivalent Standard Axle Load |
| HGV | – | Heavy Goods Vehicles |
| HDM-4 | - | Highway Development and Management Tool |
| IRI | - | International Roughness Index |
| PCU | - | Passenger Car Unit |
| RUC | - | Road User Charge |

## 1. Introduction

Ideally, road maintenance funds should be allocated as and when maintenance requirements fall due. However this cannot often be achieved due to limited availability of road maintenance funds. In many developing countries, road maintenance needs are huge and available resources are not sufficient to allow all desired maintenance activities and interventions to be carried out. In any given planning period it is therefore important to consider the financial resource constraints through prioritization with the goal of achieving maximum impact and value-for-money on road maintenance expenditure. Optimal fund allocation is required both in situations with funding shortfalls and in situations with adequate funding. This is because offering a lot of resources does not necessarily mean fulfilling different points on the risk reward spectrum and misallocation could result in wastage. Limited resources also have to be maximized for optimal returns.

The traditional approach that allocates proportions of the total available road maintenance budget to road classes based on historical data is not objective or satisfactory in the eyes of many stakeholders in the road sector. A Road Fund Board requires relevant and up to date information in a variety of forms in order to analyze and to justify allocation of road maintenance funds to the different road classes and road agencies. More objectively, road fund allocation methods can be classified into two broad frameworks as Formula based and Needs based. The allocation by consultations and negotiations is subjective and could result in biases.

Under the Needs based method, the fund allocation approach is determined by the cost of treatment works for pavement deficiencies. The maintenance needs of the road network can efficiently be determined using the Highway Development and Management (HDM-4) tool, Kerali et al., 2005. HDM-4 analysis gives a gamut of routine and periodic maintenance work activities to be carried on the network for each road section. The allocation method is straight forward and simply entails subdividing the available funding in proportion to actual needs. In order to improve on the reliability of HDM-4, it must be calibrated to simulate the local conditions.

This paper describes the development of an equitable, transparent, fair and justifiable approach to allocation of road maintenance resources. The key research element is the investigation of the key relationships between road user charges and road agency costs based on the principles of efficiency and equity. It introduces a novel approach to reduce biases in road maintenance fund allocation in a country. To test the validity and demonstrate the application of the framework developed, a worked example has been presented to allocate an assumed available budget. The framework developed provides an objective way of investing in road network preservation by balancing between efficiency and equity and thereby improve decision making in road asset management.

# 2. Approach and Methodology for Developing Allocation Formula

## 2.1 Key Principles

The design of a strategy or methodology for the allocation of available funding for road maintenance cannot and should not be done without due consideration of the source of this funding. This connection between source and application is extremely important since it answers many of the questions and it simplifies the allocation problem in many respects.

A robust and defensible approach to fund allocation should take care of the following key principles:

(i) Equitable sharing of funds between road classes and designated agencies;

(ii) Since the user pays, the allocation shall be fairly representative of road usage;

(iii) Funds shall be allocated to give the optimum effect in terms of road condition;

(iv) For roads with generally low traffic levels, the social benefit of these roads shall be recognised by a significant contribution to their upkeep from the consolidated fund or other charges, lest the money allocated be wasted on inadequate maintenance. The need for counterpart funding shall also be given consideration here;

(v) The formula shall as much as possible, reflect the policies, plans and strategies of a particular country relating to the road sub-sector and also to general development (as reflected in the National Development Plan and in Millennium Development Goals); and

(vi) The validity of the formulae should be tested and verified by application to a sample of agencies.

## 2.2 Road User Charging

The system of road user charges was recently implemented in a number of countries which forms part of an international drive to reform and commercialize the road sectors by treating road sectors as a commercial business. The specific aim of road user charging is to shift the burden of road expenditure from the general taxpayers to the road user in a way that is economically efficient, equitable, and recovers the full cost of providing and maintaining roads. The system has the potential to promote efficiency in expenditure on roads and to maintain expenditure levels at lower and more stable aggregate levels than is presently the case. This can improve efficiencies in the engineering and construction industries with lower prices resulting.

The general principles for road user charging are the following:

- Principle of full cost recovery;
- Principle of economic efficiency;
- Principle of equity.

A full explanation of these principles is given by Heggie (1995). What is important though is that road user charging are based on the above principles which must also be reflected in the allocation methodology for these principles to be meaningful; the charging in itself is only one step in the process that ends in the allocation and actual maintenance of roads.

One should furthermore never forget the basic rationale behind road user charges; i.e. having the road user pay for road maintenance: The World Bank has proven that every U$1.0 of required road maintenance cost that has not been invested for this purpose will cost the road user U$3.0 in additional vehicle operating cost for the same period. This is an astounding figure that shows why road users should be in control of the payment for road maintenance since they will suffer the consequences of poor maintenance directly. Some economists go that far to state that no country should have more roads (in length) than the road user can actually afford to maintain through road user charges.

In laymen terms the meaning of the road user charges can be summarized by stating that the road user is paying for the full cost of road maintenance which must be expended on the same roads for which the charges are levied to ensure economic efficiency in terms of minimum (optimum) vehicle operation cost for the road user and minimum (optimum) road maintenance cost for the road agency while the process of allocation and expenditure must be equitable between different types of road users and between different road agencies.

The available road user charges (road fund) will always be limited. Expenditure on roads for which no charges was collected will result in a shortfall (backlog) in other areas. Inappropriate allocations (i.e. not linked to actual charging) will thus result in an endless process of trying to eliminate backlogs in one area and simultaneously creating backlogs in another area. The only way to move towards long-term sustainability and efficiency in the road sector is to allocate the funding for the purposes that it was collected in the first instance (which has a sound rationale) and then to cover the gaps with additional funding from the government and development partners.

## 2.3 Factors that Influence Road Maintenance Cost

The typical factors that determine road maintenance cost are well accurately known from the disciplines of road engineering and pavement design technology and are hence divided into primary or key determinants and secondary or contributing factors. Almost all these factors are input for the HDM-4. The factors are given in Table 1.

**Table 1: Factors that Influence Road Maintenance Cost**

| **Primary Factors** | **Main Secondary Factors** |
|---|---|
| • Length of road<br>• Surface type (Bituminous, Gravel, Earth)<br>• Annual average daily traffic (AADT) and percentage of heavy goods vehicle (HGV)<br>• Condition of road (Good, Fair, Poor)<br>• Design standard of road<br>• Maintenance policy/strategy | • Climate of Area – Wet or Dry; Hot or Cold<br>• Topography of the area<br>• Geology – in terms of availability of suitable materials<br>• Location relative to suitable material & equipment<br>• Demand and supply of road infrastructure<br>• International fuel price –energy input<br>• Inflation and price adjustment factors |

A much longer list can be formulated of all the secondary and contributing factors. However it suffices to say that the first six factors describes and determines more than 80% of the typical variability in road maintenance cost.

## 2.4 Roads in Maintainable State

It is recommended that road maintenance funds should be allocated to roads in maintainable condition or state. Therefore the first step in the allocation process involves determination of the roads in maintainable state and defining the input data required. Threshold values for road condition need to be defined by a road authority that can be used to screen roads in maintainable state. A typical example of threshold values for road condition based on roughness is given in Table 2. The appropriate definition is that roads in poor and bad condition threshold form non-maintainable part of the network and the rest form part of the maintainable network.

**Table 2: Ride Quality Threshold Values for Paved and Unpaved Roads**

| IRI Band | Description | Paved Roads IRI in m/km | | Unpaved Roads IRI in m/km | |
|---|---|---|---|---|---|
| | | Range | Representative Value | Range | Representative Value |
| Good | Ride very smooth and very comfortable; No/slight unevenness of the profile; No rutting or potholes | <4 | 3.5 | <5 | 4 |
| Fair | Moderate unevenness of the profile; Moderate rutting but not potholes | 4 – 5 | 4.5 | 5 – 9 | 7 |
| Poor | Frequent unevenness of the profile and significant rutting | 5 - 7 | 6 | 9 - 16 | 12.5 |
| Bad | Severe unevenness on paved roads. Unpaved roads impassable except by 4-Wheel Drive | >7 | 9 | >16 | 18 |

## 2.5 Proposed Allocation Structure

A three-stage allocation structure is proposed as illustrated in Figure 1. The first step in the allocation process involves determination of the roads in maintainable state and defining the input data required. This is then followed by the three-stage allocation structure which consists of the following:

- Stage 1 – allocates available funding to surface types;
- Stage 2 – allocates the funding per surface type between the road network jurisdictions;
- Stage 3 – allocates the funding per road network and surface type to the designated authorities within each district, town councils, municipals, and sub-counties

For this study, three road surface types (i.e. paved, gravel and earth) and five road network jurisdictions (i.e. National, District, Town Council, Municipal and Community) were considered.

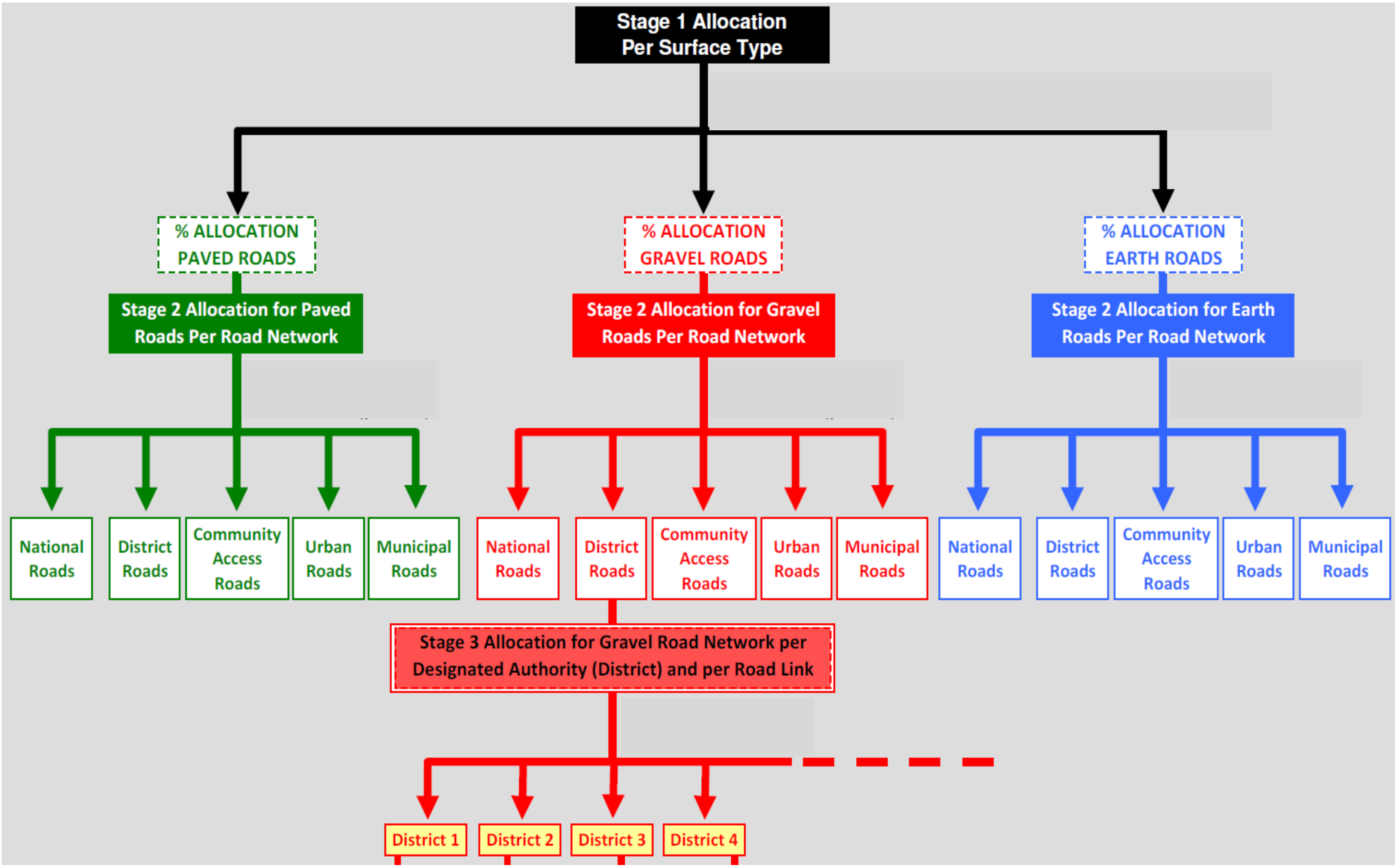
## 2.6 Allocation Criteria

The proposed road fund allocation formula is based on the following criteria depending on the allocation stage. The two most significant parameters for the allocation of road maintenance funds are traffic and road length. Traffic need to be considered in terms of both volume and loading.

**Stage 1**

1. *Vehicle utilization* – to reflect on the principle of user pays. The allocation parameters considered here are:
   - traffic volume measured in passenger car unit kilometres (PCU-Km), and
   - traffic loading in equivalent standard axle load kilometres (ESAL-Km)

**Figure 1: Flow Chart – The three stage allocation structure**



2. *Road length* – to reflect maintenance requirements in terms of extent/size. This also takes into account the effect of non-traffic related elements on road deterioration (e.g. environmental factors) and routine maintenance needs.
3. *Road asset value* – to reflect the investment that needs to be preserved in the interest of national economy and wealth generation.
4. *Optimum maintenance requirements* - to reflect the fact that different road surface types and standards require different levels of funding to maintain it to an acceptable condition. This is expressed in terms of the ratios of optimum maintenance cost for each road surface type. Road surface types that require higher funding for their optimal level of maintenance should receive higher allocations.

**Stage 2**

1. *Vehicle utilization* – to reflect on the principle of full cost recovery that maintenance cost of roads should be recovered from road users. The most trafficked roads generate most revenue for the road fund and conversely should get higher allocations. The parameters considered are:
   - traffic volume measured in passenger car unit kilometres (PCU-Km), and
   - traffic loading in equivalent standard axle load kilometres (ESAL-Km)

2. *Road functional class* priority and the key role of supporting the most highly ranked national objective of promoting economic growth and wealth creation. This is expressed in terms of relative weights for the different road networks (i.e. the designated road agencies). Road classes with higher relative weight should receive higher allocations.

3. *Other sources of road maintenance funding* – road agencies or networks that possess other sources of raising funds (e.g. through vehicle parking charges, taxation, etc.) should receive less allocations.

**Stage 3**

For Urban, Municipal and District networks the parameters considered are the following:

1. *Vehicle utilization* – the most trafficked roads deteriorate faster thus generating higher maintenance needs therefore it is essential that these get higher allocations. The parameters considered are the same as for Stage 1 above.
2. *Road length* – to reflect maintenance requirements in terms of extent of the road network. Designated authorities with bigger network size should receive higher allocations.
3. *Equity* – to reflect social concerns and needs of the population regardless of which area they live in. Every designated authority should receive a minimum fixed amount of funding expressed as a percentage of the available fund for each network (urban, municipal or district).
4. *Climatic factors* - rainfall is a major climatic factor that influences road deterioration. Roads in areas with high rainfall will deteriorate faster resulting into more frequent and higher maintenance requirements. These areas should therefore get proportionally higher allocations.
5. *Variations in unit costs of road works across the country*. There are several factors that lead to variations in unit costs of works and this influences the total amount of road maintenance fund requirements by designated authorities. Designated authorities with high unit costs of works should get higher allocations, on average.

For Community and Access Roads the parameters considered include all those given above for urban, municipal and district networks but excluding vehicle utilization since all these roads are carry very low traffic volumes with little variations. Another important parameter considered for CAR maintenance fund allocation is population of the area. Population is considered a surrogate for travel demand and needs for social services. Areas with big population should get higher allocations.

# 3. Allocation Formula Development

## 3.1 General

The allocation criteria based for the various stages of the allocation process were used as the basis for developing the road maintenance fund allocation formulae. The formulae developed for the allocation of road maintenance funds can be used for both vertical and horizontal allocation.

The allocation formulae proposed are deterministic, where funds are allocated as a precise value on the basis of mathematical functions of known relevant quantified variables. It is important to appreciate that models are simplified representations of reality used to study effects of policies, strategies, programmes and designs. The two general classes of deterministic models used for road management are mechanistic and empirical.

***Mechanistic*** models are based on first principles and knowledge of the physical laws governing the fundamental theories of behaviour of a system. They are usually very data intensive and rely on parameters which are difficult to quantify in the field.

***Empirical*** models are usually based on statistical analyses of locally observed behavior or trends, and may not be applicable outside the specific conditions upon which they are based.

To develop the allocation formulae, the **structured mechanistic-empirical** approach was adopted, which is similar to that used by Paterson (1987*)* for developing road performance models. This is based on identifying the functional form and primary variables affecting each stage of fund allocation from both first principles and empirical information and then using various statistical techniques to quantify their impacts. This has the advantage that the resulting formulae combine both the theoretical bases of mechanistic models with the behaviour observed in empirical studies.

## 3.2 Development of Formula - Stage 1: Allocation to Road Surface Types

The assumptions made in developing Stage 1 allocation formula are the following:

1. Roads of different surface types deteriorate at different rates, and the rate of deterioration depends on the level of vehicle utilization among other factors such as the climate. Also different categories of road users cause different levels of road deterioration which should be offset by maintenance interventions. The cost of maintenance intervention should be shared equitably among users. That is to reflect on the principle of user pays. The higher the level of utilization the higher the amount paid by the user. The allocation parameters considered there are: traffic volume measured in passenger car unit kilometers (PCU_Km), and traffic loading in equivalent standard axle load kilometers (ESAL-Km)
2. Maintenance requirements depend partly on the extent and size of the road network. The larger the network the bigger is its maintenance requirements.

3. To reflect the investment that needs to be preserved in the interest of national economy and wealth generation, it is important to take into account the asset value of the road type. The asset value will depend on the road surface type. Paved roads have higher asset value per kilometer length than gravel and earth roads.

4. In the absence of stringent budget constraints, the roads should receive both technically and economically optimum and timely maintenance interventions. The cost associated with optimum maintenance is considered in the allocation formula to reflect the fact that different road surface types and standards require different levels of funding to maintain them to an acceptable condition. This is expressed in terms of the ratios of optimum maintenance cost for each road surface type. Road surface types that require higher funding for their optimal level of maintenance should receive higher allocations.

5. Traffic and Length are the two most important factors in the formula. Therefore the percentage contribution of impact, measured in terms of the amount of funds allocated to each road surface type, will be higher for the parameters associated with these two factors.

From the above assumptions, a conceptual formula for Stage 1 allocation is expressed as follows:

$$M_s = P_s * B \qquad \text{Equation 1}$$

Where, $M_s$ is the allocation to road surface type $s$; B is the total available budget to the Road Fund and $P_s$ is a parameter defined as function $f$(traffic, road length, asset value, and maintenance cost) for road surface type $s$.

## 3.3 Development of Formula for Stage 2 – Allocation to Networks

The assumptions made in developing Stage 2 allocation formula are the following:

1. The most trafficked roads generate most revenue for the road fund and conversely should get higher allocations. The parameters considered are for vehicle utilization: traffic volume measured in passenger car unit kilometers (PCU-Km), and traffic loading in equivalent standard axle load kilometers (ESAL-Km). This reflects on the principle of full cost recovery that maintenance cost of roads should be recovered from road users.

2. The formula should include road functional class priority defined in terms of the key role of supporting the most highly ranked national objective of promoting economic growth and wealth creation. This is expressed in terms of relative weights for the different road networks (i.e. the designated road agencies) defined as the perceived proportional contribution of the road functional class to the overall national objective of promoting economic growth and wealth creation. Road classes with higher relative weights should receive higher allocations.

3. Although road agencies or networks that possess other sources of raising funds (e.g. through vehicle parking charges, taxation, etc.) should receive less allocations, the assumption is made that this should not be considered in the conceptual formula. Instead this issue should be addressed within the overall allocation process at the stage of consultation with the Agencies. Therefore no percentage contribution for agencies that have significant local revenue will be considered in Stage 2 formula.

4. Road length is included implicitly in Stage 2 formula through the parameters PCU-Km and ESAL_Km. Hence, there is no need to include length again explicitly as a separate parameter in the formula to avoid the issue of redundancy or double counting of effects.

From the above assumptions, a conceptual formula for Stage 2 allocation to road surface types under Sub-Networks is proposed as follows:

$$M_{sj} = W_j * Q_j * M_s \qquad \text{Equation 2}$$

Where, $M_{sj}$ is the allocation to road network j (j = national, district, town council, municipal or CAR); $M_s$ is the allocation to road surface type *s* (obtained from Stage 1); $W_j$ is the relative weight based on perceived proportional contribution of each road hierarchy and functional class to the overall national objective of promoting economic efficiency for road network j and $Q_j$ is a parameter defined as function $f$(traffic, road length).

## 3.4 Development of Formula for Stage 3 – Allocation to Designated Road Agencies

Allocation to designated agencies at Stage 3 uses formulae developed separately for town councils, municipals and district roads and for community and access roads. The key assumptions made in developing Stage 3 allocation formulae are given below.

For Town Councils, Municipal and District networks:

1. The most trafficked roads deteriorate faster thus generating higher maintenance needs therefore it is essential that these get higher allocations. The parameters considered are: traffic volume measured in passenger car unit kilometers (PCU-Km), and traffic loading in equivalent standard axle load kilometers (ESAL-Km).
2. Road length should be included in the formula to reflect maintenance requirements in terms of extent of the road network. Designated agencies with bigger network size should receive higher allocations.
3. Traffic and Length are the two most important factors in the formula. Therefore the percentage contribution of impact, measured in terms of the

amount of funds allocated to each designated agency, will be higher for the parameters associated with these two factors.

4. Social concerns and needs of the population should be considered regardless of which area they live in. Every designated agency should therefore receive a minimum fixed amount of funding expressed as a percentage of the available fund for each network (town council, municipal or district).

5. Rainfall is a major climatic factor that influences road deterioration. Roads in areas with high rainfall will deteriorate faster resulting into more frequent and higher maintenance requirements. These areas should therefore get proportionally higher allocations.

6. Variations in unit costs of road works across the country should be included in the allocation formula. There are several factors such as road density, topography, geology, terrain that lead to variations in unit costs of works and this influences the total amount of road maintenance fund requirements by designated agencies. Designated agencies with high unit costs of works should get higher allocations, on average.

7. For Community and Access Roads the parameters considered include all those given above for town council, municipal and district networks but excluding vehicle utilization since all these roads carry very low traffic volumes with little variations. Another important parameter considered for CAR maintenance fund allocation is population of the area. Population is considered a surrogate for travel demand, attractiveness of an area and needs for social services. Areas with big population should get higher allocations.

For allocation to town councils, municipalities and districts, the conceptual formula is given by the following expression:

$$M_{sz} = Q_z * R_z * E * M_{sj} \qquad \text{Equation 3}$$

Where, $M_{sz}$ is the allocation to designated agency *z* for road surface type *s*; $M_{sj}$ is the allocation to road network jurisdiction j and road surface s (obtained from Stage 2); $Q_z$ is a parameter defined as function *f*(traffic, road length); $R_z$ is a parameter defined as function *f*(climate, unit cost), and E is a parameter defined as function *f*(equity, social concerns).

For allocation to Community Access Roads the conceptual formula is given by the following expression:

$$M_{sz} = D_z*R_z*E*M_{sj} \qquad \text{Equation 4}$$

Where, $M_{sz}$ is the allocation to designated agency *z* for road surface type *s*; $M_{sj}$ is the allocation to road network jurisdiction j and road surface *s* (obtained from Stage 2); $D_z$ is a parameter defined as function *f*(population, road length); $R_z$ is a parameter defined as function *f*(climate, unit cost); and E is a parameter defined as function *f*(equity, social concerns).

## 3.5 Input Data

The formulae input data can be considered in two groups: (i) Variable data; and (ii) Fixed coefficients and factors (temporarily fixed because of the need for updating the values over time).

Table 3 provides sources of the variable input data required for the proposed allocation formula.

**Table 3: Variable Input Data Sources**

| **Data Type** | **Units** | **Possible Sources of Data** |
|---|---|---|
| Road Length | Km | Designated road agencies |
| Asset Value | Currency | Estimated from replacement costs of roads and the extent (length) of roads by surface type. |

| | | |
|---|---|---|
| Traffic Volume | PCU_km | Traffic volume should be requested from designated agencies. |
| Traffic Loading | ESAL_km | Traffic loading should be elicited from reports on axle load surveys available from the designated agencies. |
| Population | No. | Population data may be obtained from Uganda Bureau of Statistics. |

The formulae coefficients and factors relate to climatic zones, unit costs of maintenance works, equity and social concerns.

## 3.6 Operationalization of the Allocation Formula

The overall allocation procedure is illustrated in Figure 2. The allocation procedure requires that the input data, including the available fund to be allocated, should be determined and provided at the start of the process. Stage 1 is a vertical allocation to the different road surface types that is performed using the formula developed. Then Stage 2 allocation to the different road networks (i.e. horizontal allocation) is performed. After this stage, the results obtained will be compared (e.g. with road network maintenance needs and the impact of these allocations on the network performance) to determine whether or not these are satisfactory. Consult with the agencies and address issues such as percentage contribution for agencies that have significant local revenue and counterpart funding. If the outcome appears to be unsatisfactory then some fine-adjustments need to be made on the values of the model coefficient and factors and the allocation process repeated from Stage 1 to Stage 2. If the results obtained after Stage 2 are satisfactory then the allocation process continues to Stage 3.

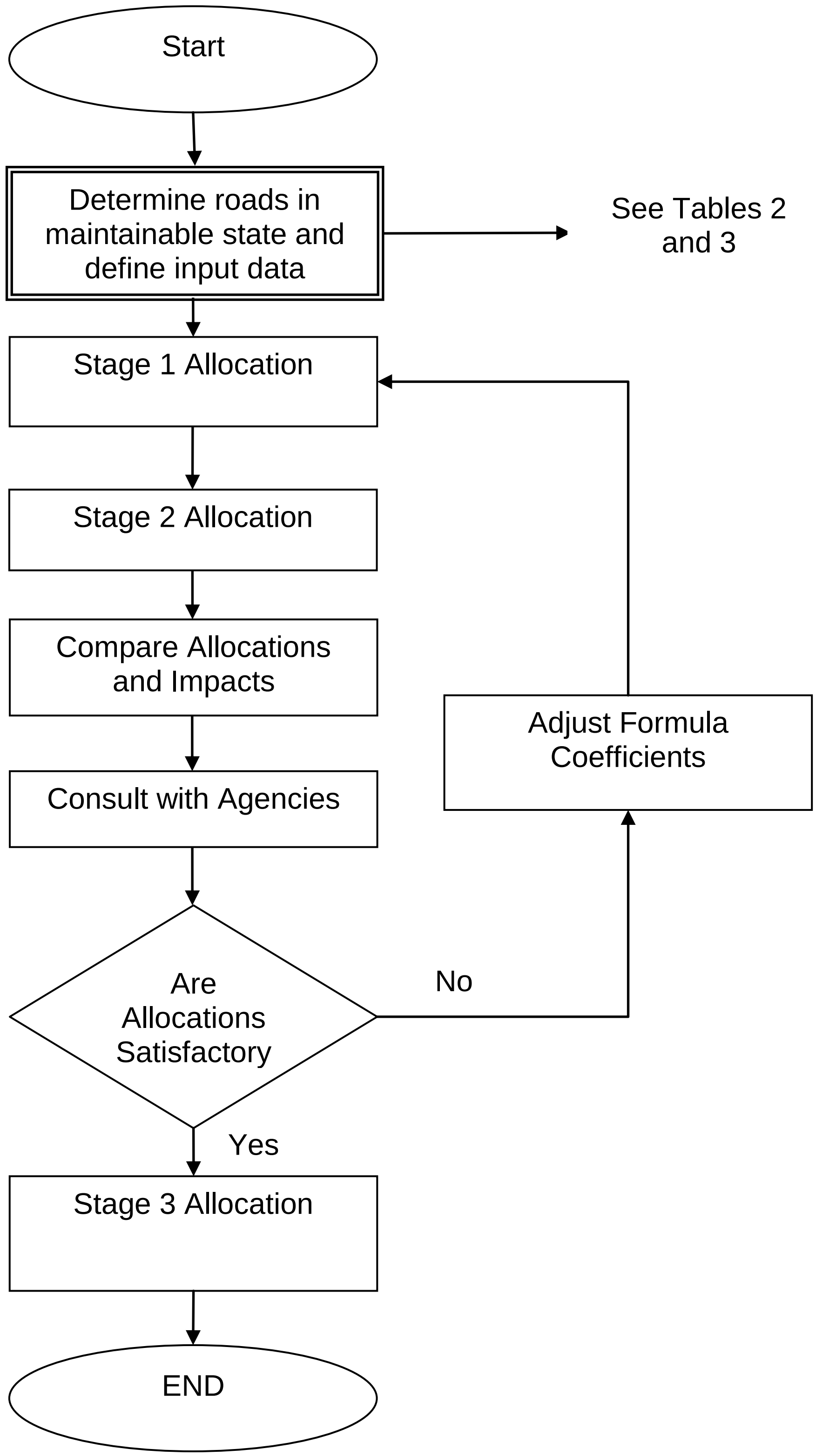



**Figure 2: Overall Allocation Process**

## 4. Application of Formula – A Case Study

The application of the formula described in this paper was tested using data obtained from Uganda Road Fund. The results of Stage 1 and Stage 2 allocations are shown below assuming an available budget of US Dollars 200 million. A meaningful demonstration of allocations at stage 3 requires input data on population for each designated district, urban area and municipality.

### 4.1 Stage 1 Allocation – Vertically

The required input data and assumptions for this vertical allocation stage is summarized in Table 3.

**Table 3: Stage 1 Input Data and Assumptions**

| Road Category | PCU-km | ESAL-km (in millions) | Asset Value (in million US$) | $Copt_s$ | Length (in Km) |
|---|---|---|---|---|---|
| Paved | 18,816,415 | 6.91 | 1,519 | 1.00 | 5,754 |
| Gravel | 8,510,238 | 3.12 | 197 | 0.30 | 52,946 |
| Earth | 631,585 | 0.23 | 142 | 0.03 | 74,214 |

*Notes to Table 3:*

1. PCU-km is the total traffic volume in passenger car unit kilometers for each road surface type (paved, gravel or earth).
2. ESAL-Km is the total traffic loading in equivalent standard axle loads kilometers for each road surface type.
3. Asset Value (AV) is the asset value of road surface type.
4. Copts are the relative weights for optimal maintenance cost for road surface type *s* (*s* = paved, gravel or earth)
5. Length (Ls) denotes the Road Network length by surface type s

The relative allocations at stage 1 are given in Table 4.

**Table 4: Stage 1 Relative Allocations**

| Road Type (S) | Traffic Component | | | Asset Value | Maintenance Costs and Length | | Stage 1 Allocation |
|---|---|---|---|---|---|---|---|
| | Volume (V) | Loading (E) | (V+E) | | (Copts*Ls) | Relative (Copts*Ls) | |
| Paved | 0.47 | 0.20 | 0.67 | 0.82 | 5,754 | 0.24 | 54% |
| Gravel | 0.21 | 0.09 | 0.30 | 0.11 | 15,884 | 0.67 | 40% |
| Earth | 0.02 | 0.01 | 0.02 | 0.08 | 2,226 | 0.09 | 6% |
| Total | 0.70 | 0.30 | 1.00 | 1.00 | 23,864 | 1.00 | 100% |

## 4.2 Stage 2 Allocation - Horizontally

The inputs to the allocation formula at Stage 2 are provided in Table 5 by surface type and road network. These inputs must be consistent with those used at Stage 1 allocation.

**Table 5: Stage 2 Inputs**

| Road Category | Notation | National | District | Municipality | Town Council | CAR |
|---|---|---|---|---|---|---|
| Paved | PCU-km | 11,441,433.1 | 0 | 1,671,014.8 | 3,364,491.0 | 0.0 |
| | ESAL-Km | 4.2 | 0 | 0.6 | 1.8 | 0.0 |
| Gravel | PCU-km | 3,302,825.1 | 4,531,642.4 | 143,518.9 | 312,444.5 | 219,806.9 |
| | ESAL-Km | 1.2 | 1.7 | 0.1 | 0.2 | 0.1 |
| Earth | PCU-km | 0.0 | 20,583.8 | 61,759.4 | 62,128.0 | 487,482.6 |
| | ESAL-Km | 0.00 | 0.01 | 0.02 | 0.05 | 0.18 |

Relative allocations derived using Stage 2 formula is summarized in Table 6.

**Table 6: Stage 2 Allocation by Road Network**

| Road Type | National | District | Municipality | Town Council | CAR |
| --- | --- | --- | --- | --- | --- |
| Paved | 162 | 0 | 17 | 39 | 0 |
| Gravel | 76 | 74 | 2 | 6 | 2 |
| Earth | 0 | 1 | 3 | 4 | 14 |
| **Total** | 238 | 75 | 22 | 48 | 16 |
| **% Allocations** | **59%** | **19%** | **6%** | **12%** | **4%** |

## 4.3 Sensitivity Analysis

Sensitivity of the proposed model to changes in key input variables of traffic volume, traffic loading, asset value and road length was assessed and the results are illustrated in Figure 3. Considering Figure 3, the horizontal axis represents the percentage change in input parameter (i.e. traffic volume, traffic loading, asset value or road length) while the vertical axis denotes the percentage change in paved roads allocation. Traffic volume was found to be the most sensitive parameter with a 50% change in input value resulting in a 6% change in allocation. The results suggest that the proposed formula is generally robust to changes in key input variables.

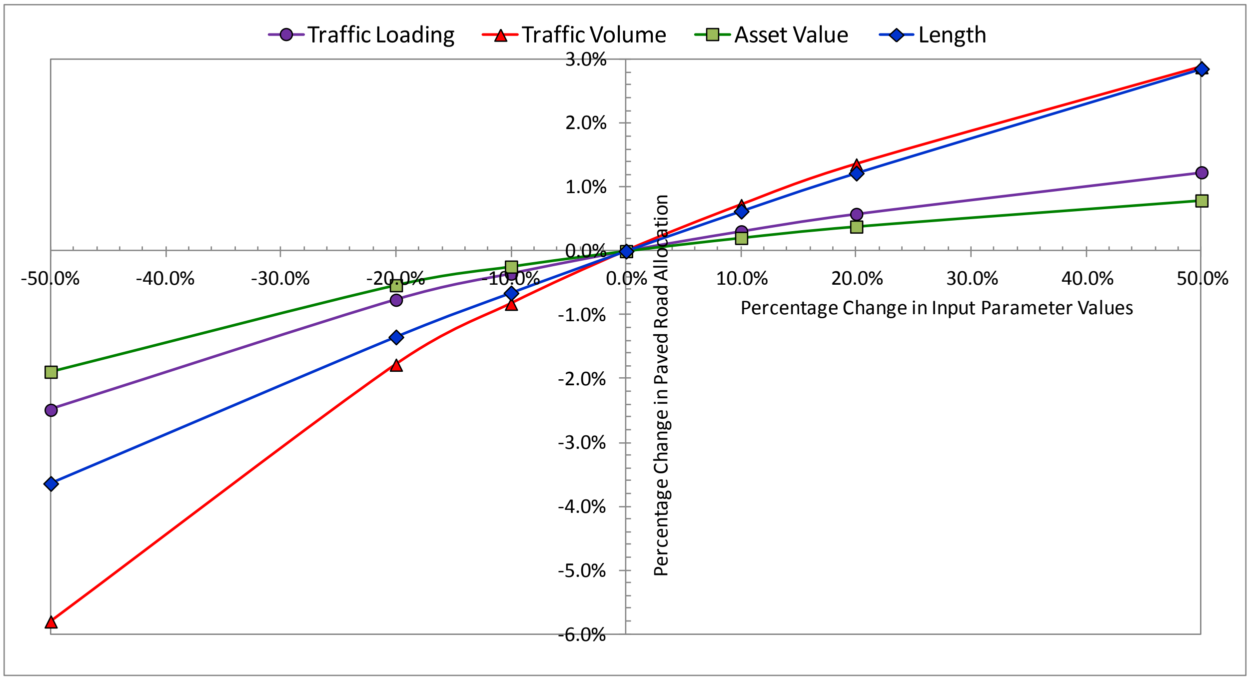



**Figure 3: Sensitivity of Key Input Variables**

## 5. Conclusions

This paper describes the development of an equitable, transparent, fair and justifiable framework for allocation of road maintenance resources. The framework comprises a set of mathematical formulae that can be adapted for use by a Road Fund Board to allocate road maintenance funds vertically between road classes and horizontally between designated agencies responsible for each class of road. The key research element is the investigation of the key relationships between road user charges and road agency costs based on the principles of efficiency and equity. It introduces a novel approach to reduce biases in road maintenance fund allocation in a country.

This formula-based approach is relatively simple and although it does not require any prior knowledge of the actual maintenance cost, knowledge of the relative maintenance cost per km for the various surface types is required. This methodology however does not create and maintain a direct linkage over time between the actual modeled maintenance costs and the allocated funding.

It is recommended that Road Fund Boards should consider the proposed "Three-Stage Allocation Formula" which addresses the weaknesses with the traditional methods of road maintenance fund allocation.

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