



Case Study: HDM-4 adaptation for analyzing Kenya roads

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ACRONYMS AND ABBREVIATIONS

AADT	-	Annual Average Daily Traffic
BCR	-	Benefit Cost Ratio
ESALF	-	Equivalent Standard Axle Load Factor
FYRR	-	First Year Rate of Return
HDM-4	-	Highway Development and Management Tool
IQL	-	Information Quality Level
IRI	-	International Roughness Index
IRR	-	Internal Rate of Return
KeNHA	-	Kenya National Highways Authority
KeRRA	-	Kenya Rural Roads Authority
KRB	-	Kenya Roads Board
KURA	-	Kenya Urban Roads Authority
KWS	-	Kenya Wildlife Services
MCA	-	Multi-Criteria Analysis
MT	-	Motorized Transport
MOTI	-	Ministry of Transport and Infrastructure
MTRD	-	Materials Testing and Research Department
NMT	-	Non-motorized Transport
NPV	-	Net Present Value
NTSA	-	National Transport and Safety Authority
PCSE	-	Passenger Car Space Equivalent
RAC	-	Road Agency Cost
RSIP	-	Road Sector Investment Programme
RSIP TF	-	Road Sector Investment Programme Task Force
RUC	-	Road User Cost
RUE	-	Road User Effects
VOC	-	Vehicle Operating Costs

1 Introduction

This paper presents a case study to adapt the highway development and management tool (HDM-4) for investigating road investment choices in Kenya. Roads constitute the most important mode of transport in Kenya since more than 93% of all freight and passenger traffic is transported by road. Kenya's public road network comprises some 161,451km of which 14,561km is paved while 146,890km is unpaved. The estimated value of the road asset is KShs 2.5 trillion and this represents a significant portion of the country's public investments. Given its contribution to the country's socioeconomic development and the public investment it represents, the roads network must be continuously developed, managed and maintained in a prudent and effective manner.

There is currently a widespread recognition in Kenya of the importance of road development and maintenance and the value placed on the issue both by users and the wider community. There is also an increasing understanding of the serious consequences of failure to invest adequately and effectively in maintaining the national road network. For this reason, the Government of Kenya desires to have an objective and scientific system to assist decision-makers in the allocation of resources for road maintenance and development that is consistent with the actual needs of the road network. It also wants to have better appreciation of the effect of various investment levels and its long-term impact on the condition of the road network, the road users and the environment. In the allocation of resources, there is need to have a mechanism that ensures optimum and equitable distribution that avoids skewedness to any class or type of road within the network. In the face of scarce resources, the determination of road investment priorities that yield maximum returns to the economy of Kenya is also of concern to the Government.

The adoption of HDM-4 by the Ministry of Transport and Infrastructure and its agencies is therefore aimed at improving decision-making on expenditures in the road sector by enabling effective and sustainable utilisation of the latest Highway Development and Management (HDM-4) knowledge.

This case study constitutes a broader assignment commissioned by Kenya Roads Board (KRB) with the following objectives:

- (i) To improve the configuration and calibration parameters of HDM-4 Kenyan Workspace. The update of configuration and calibration parameters will be done for the latest version of HDM-4 (Version 2.08).
- (ii) In close consultation with the Road Sector Investment Programme Task Force (RSIP TF), develop a detailed short term 5 year Road Sector Investment Programme (2015 - 2019) anchored on long term sector plans (including the 15 year RSIP) and national priorities.

2 HDM-4 Analytical Framework

2.1 Introduction

The basic unit of analysis in HDM-4 is the homogeneous road section. Several investment options can be assigned to a road section for analysis. The vehicle types that use the road must also be defined together with the traffic volume specified in terms of the annual average daily traffic (AADT).

The analytical framework of HDM-4 is based on the concept of pavement life cycle analysis, which is typically 15 to 40 years depending on the pavement type. This is applied to predict road deterioration (RD), road works effects (WE), road user effects (RUE), and socio-economic and environmental effects (SEE) (Odoki and Kerali, 2006). The underlying operation of HDM-4 is common for the project, programme or strategy applications. In each case, HDM-4 predicts the life cycle pavement performance and the resulting user costs under specified maintenance

and/or road improvement scenarios. The agency and user costs (i.e. RAC and RUC, respectively) are determined by first predicting physical quantities of resource consumption and then multiplying these by the corresponding unit costs.

Two or more options comprising different road maintenance and/or improvement works should be specified for each candidate road section with one option designated as the base case (usually representing minimal routine maintenance). The benefits derived from implementation of other options are calculated over a specified analysis period by comparing the predicted economic cost streams in each year against that for the respective year of the base case option. The discounted total economic cost difference is defined as the net present value (NPV). Other economic indicators calculated are the internal rate of return (IRR), benefit-cost ratio (BCR) and first year rate of return (FYRR). The average life cycle riding quality measured in terms of the international roughness index (IRI) is also calculated for each option.

2.2 Overall Logic Sequence

The overall logic sequence for economic analysis and optimisation is illustrated in Figure 1. This figure shows the following (Odoki and Kerali, 2006):

The outer analysis loop - enables economic comparisons to be made for each pair of investment options, using the effects and costs calculated over the analysis period for each option, and it allows for variations in generated and diverted traffic levels depending on the investment option considered.

The inner analysis loop - shows how annual effects and costs to the road agency and to the road users, and asset values are calculated for individual road section options.

Optimisation procedures and budget scenario analysis - these are performed after economic benefits of all the section options have been determined.

Multiple criteria analysis (MCA) - provides a means of comparing investment options using criteria that cannot easily be assigned an economic cost. Note that this capability has not been used in the present study.

2.3 Data Requirements

The main data sets required as inputs for HDM-4 analyses are categorised as follows (Kerali et al., 2000):

- (i) *Road network data* comprising: inventory, geometry, pavement type, pavement strength, and road condition defined by different distress modes;
- (ii) *Vehicle fleet data* including vehicle physical and loading characteristics, utilisation and service life, performance characteristics such as driving power and braking power, and unit costs of vehicle resources;
- (iii) *Traffic data* including details of composition, volumes and growth rates, speed-flow types and hourly traffic flow pattern on each road section;
- (iv) *Road works data* comprising historical records of works performed on different road sections, a range of road maintenance activities practised in the country and their associated unit costs.
- (v) *Economic analysis parameters* including time values, discount rate and base year.

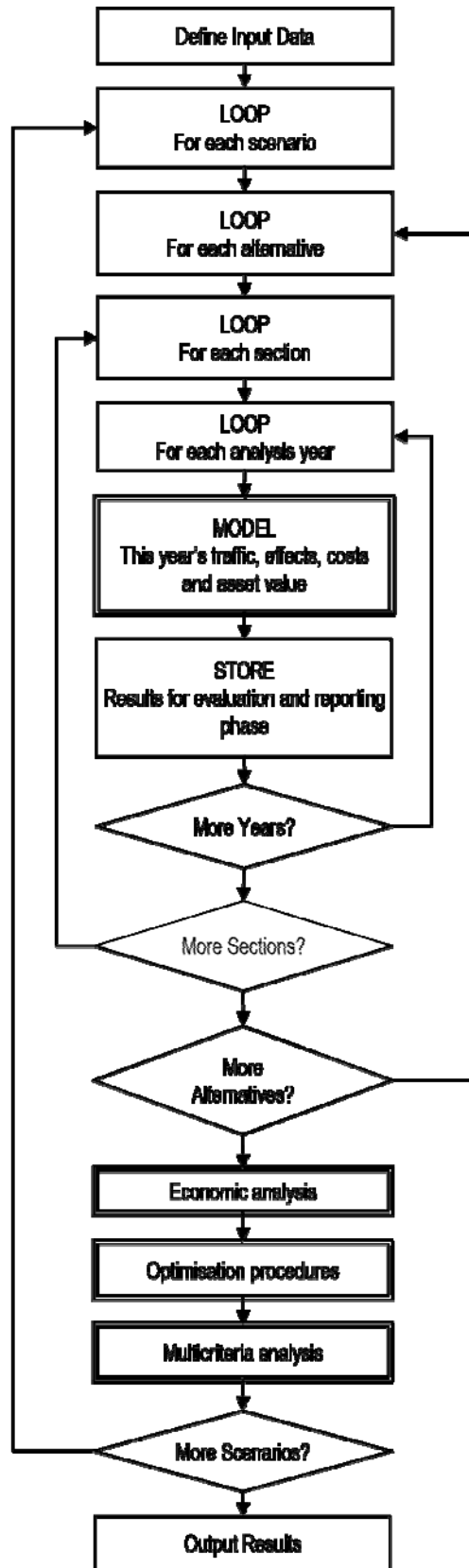


Figure 1: HDM-4 Analytical Framework

2.4 Reliability of results

The reliability of the results obtained from HDM-4 analysis is dependent upon two primary considerations (Bennett and Paterson, 2000):

- How well the data provided to the model represent the reality of current conditions and influencing factors, in the terms understood by the model; and,
- How well the predictions of the model fit the real behavior and the interactions between various factors for the variety of conditions to which it is applied.

Application of the model thus involves two important steps:

- (i) *Data input*: a correct interpretation of the data input requirements, and achieving a quality of input data that is appropriate to the desired reliability of the results.
- (ii) *Calibration of outputs*: adjusting the model parameters to enhance how well the forecast and outputs represent the changes and influences over time and under various interventions in Kenya. Calibration of the HDM model focuses on the components that determine the physical quantities, costs and benefits predicted for the Road Deterioration and Works Effects (RDWE), Road User Effects (RUE), Traffic Characteristics and Socio-Economic Effects (SEE) analysis.

The accuracy required of the input data is dictated by the objectives of the analysis. For a very approximate analysis there is no need to quantify the input data to a very high degree of accuracy. Conversely, for a detailed analysis it is important to quantify the data as accurately as is practical given the available resources.

Figure 2 illustrates the impact of the accuracy of input data on road deterioration predictions and the timing of future maintenance interventions (Bennett and

Paterson, 2000). HDM-4 uses incremental-recursive models and the existing condition (denoted by point 1 or 2) is the start point for the modelling. The pavement will deteriorate and reach that condition, defined by a given set of criteria for maintenance intervention, in a certain period of time depending on the existing condition. The difference in the start point will have as great, if not greater impact, on when the treatments are triggered as will the calibrated deterioration factor. Figure 2 also illustrates a second point: That HDM-4 model predictions are based on the mean deterioration rate and therefore will have a certain time interval within which a particular treatment will be triggered by a given set of intervention criteria. Typical values that define the slower and faster rates of deterioration into a band vary across the different distresses modelled. The further into the future one predicts the deterioration, the greater the spread in the trigger interval. Consequently, this will impact on the analysis results as costs incurred in the future are discounted to the base year value.

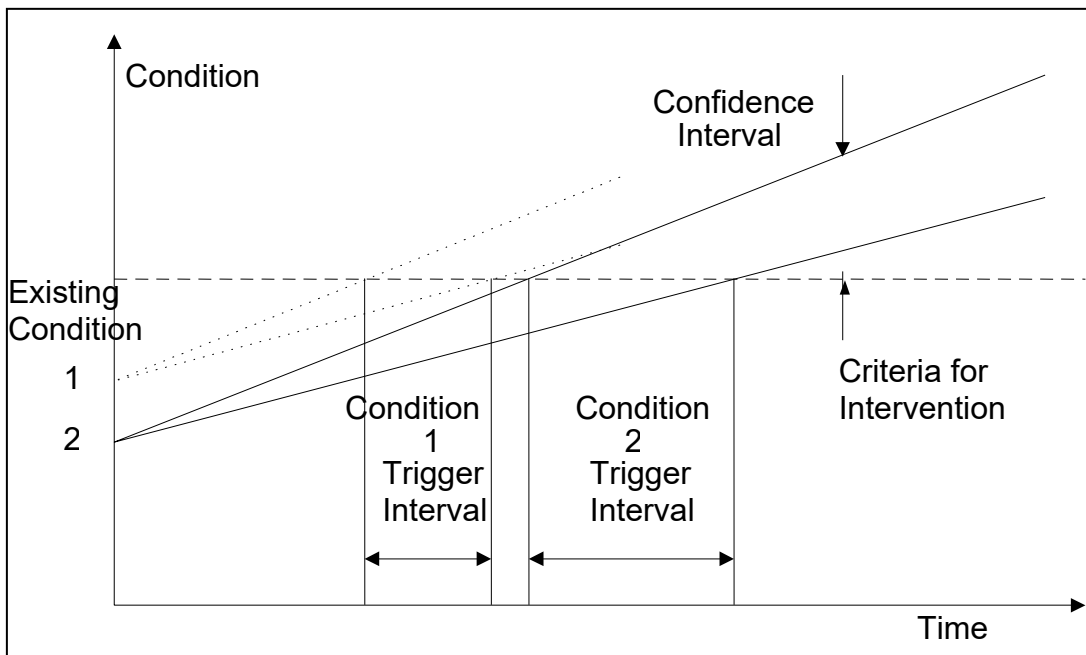


Figure 2: The impact of the accuracy of data on road deterioration predictions

3 Configuration and Calibration of HDM-4

The adaptation of HDM-4 for analysing Kenya roads involves two major activities: configuration and calibration. Each of these is outlined below. Prior to using HDM-4 for the first time in any country, the system should be configured and calibrated for local use.

3.1 Configuration

The primary objective of configuration is to make the analysis from the model relevant and compatible to the environment in Kenya by restructuring default configuration data in line with local conditions, standards and practices. HDM-4 configuration shall involve a number of activities that include the following:

- (i) Provision of information on the climatic conditions prevailing in Kenya, different road types and functional classes, and the pavement types that constitute the road network.
- (ii) Definition of the general characteristics of traffic flow on the different road types in the network; the traffic bands, traffic composition by representative vehicle types and traffic growth rates pertaining to each road type/class. Types of accidents predominant on each road type and accident rates have to be determined.
- (iii) Definition of road surface condition in aggregate form (e.g. good, fair, poor) based on measures of surface distresses (e.g. cracking, ravelling, rutting, potholes, edgebreak, roughness, thickness of gravel) to conform to local standards and practices.
- (iv) General assessment of quality of road construction in Kenya using strict adherence to technical specifications and design standards as a measure of full compliance in order to reflect local quality control regime.
- (v) Estimation of pavements strength of the various road types and classes expressed in terms of structural number and deflection.

3.2 Calibration

The calibration of HDM-4 to local conditions aims to improve the accuracy of predicted pavement performance and vehicle resource consumption. The extent of HDM-4 calibration may be defined as follows:

1. Level 1: Determines the values of required input parameters based on a desk study of available data and engineering experience of pavement performance, adopts many default values and calibrates the most sensitive parameters with best estimates
2. Level 2: Requires measurement of additional inputs and moderate field surveys to calibrate key predictive relationships to local conditions
3. Level 3: Experimental data collection required to monitor the long-term performance of pavements within the study area, which data should be used to enhance the existing predictive relationship or to develop new and locally specific relationships for substitution in the source code for the model

For this study, the target level of the calibration study is Level 2 calibration (provided suitable data is available), and the calibration will concentrate on the most important parameters as measured by impact sensitivity. The selection of parameters for calibration will be guided by the HDM-4 sensitivity classes as listed in Table 1.

Table 1: HDM-4 Sensitivity Classes

Impact	Sensitivity class	Impact elasticity
High	S-I	> 0.50
Moderate	S-II	0.20 - 0.50
Low	S-III	0.05 - 0.20
Negligible	S-IV	< 0.05

Source: HDM-4 Series Volume 5 "A Guide to Calibration and Adaptation".

In identifying data to be collected, HDM-4 Volume 5 documentation series provides guidance which recommends that efforts should be based on the results of these sensitivity analyses. Those data items or model coefficients with moderate to high impacts (S-I and S-II) should receive the most attention. The low to negligible impact (S-III and S-IV) items should receive attention only if time or resources permit.

4 Necessary improvement to existing Kenya HDM-4 workspace

The main weaknesses of the existing Kenya HDM-4 workspace that demonstrate the need to improve the configuration and calibration of HDM-4 are summarized in tables 2 and 3.

Table 2: Improvement to HDM-4 Configuration

Component	Remarks	Improvement Necessary
Traffic-Flow Pattern	There are four traffic flow patterns based on the road functional classification: (i) Traffic Flow A, (ii) Traffic Flow BC, (iii) Traffic Flow DE and Others, and (iv) Traffic Flow Urban.	These need to be reviewed and updated using available data.
Speed-Flow Types	Six types covering: (i) Single Lane with shoulders, (ii) Single Lane without shoulders, (iii) Intermediate, (iv) Two Lane standard, (v) Two Lane wide and (vi) 4-Lane or more. There are no speed reduction factors defined for conflicts between MT and NMT and for road side friction.	The speed reduction factors are important for modelling capacity improvement and these need to be defined for different road friction levels.

<p>Accident Classes</p>	<p>Accident classes are not defined in the existing workspace.</p> <p>There are no accident unit costs defined.</p>	<p>Accident classes and accident rates for different road stereotypes need to be defined based on data available with NTSA and the Police Department.</p> <p>Accident costs need to be defined for different accident types.</p>
<p>Climate Zones</p>	<p>There are 12 climate zones defined as follows: had been evolved through the use of rainfall and temperature data by previous Consultants. The climate zones as defined for Kenya are as follows: Humid Hot, Humid Cool, Sub Humid 1 Hot, Sub Humid 1 Cool, Sub Humid 2 Hot, Sub Humid 2, Cool, Semi-Arid 1 Hot, Semi-Arid 1 Cool, Semi-Arid 2 Hot, Semi-Arid Cool, Arid Hot and Arid Cool.</p>	<p>These definitions need to be validated with Kenya Meteorological Services. The objective is to align the zones with the Meteorological Services zones in order to ensure sustainability in obtaining climate data from the outfit.</p>
<p>Road Network Aggregate Data</p>	<p>The existing aggregate data definitions are mainly those defined as HDM-4 defaults.</p>	<p>Relationships between high level aggregate data and low level detailed data need to be revised and updated based on the concept of Information Quality Level (IQL). This will help to cope with missing or lack of input data necessary for HDM-4 network level analysis.</p>

Table 3: Improvement to HDM-4 Model Calibration

Component	Remarks	Improvement Necessary
Road Deterioration	The workspace does not include reasonable calibrated road deterioration (RD) model and calibration sets.	The RD models need to be calibrated in order to accurately predict the deterioration trends of different pavement types in Kenya.
Works Standards and Effects	There are no optimal work standards derived for different road functional classes.	Optimal work standards need to be defined. Unit costs of various work activities are not defined in the Work Standard.
Road User Effects	Road user effects models have been calibrated in a study conducted in 2011.	Unit costs of various vehicle resource consumption need to be updated.

Table 4 summarizes other areas that warrant improvement to Kenya HDM-4 Workspace.

Table 4: Improvement to Other HDM-4 Workspace Data

Component	Remarks	Improvement Necessary
Vehicle Fleet	Kenya has the following 10 vehicle classes: Car, 4WD & Jeep, Pick-up Utility, Mini- bus (Matatu), Small Bus, Large Bus, Light Truck, Medium Truck, Heavy Truck, Articulated Truck	The values of equivalent standard axle load factors (ESALF) given in the workspace are not correct. There are no Non-Motorised Transport defined in the Vehicle Fleet reviewed. NMT need to be included. Representative traffic growth rates need to be defined.

Worked Examples of Typical Case Studies	Only HDM-4 default case studies are available.	Typical case studies relevant to Kenya road network development and maintenance are not included.
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Furthermore, there is no HDM-4 workspace to model roads under Kenya Wildlife Services (KWS). KWS will have to provide inventory of the road network they manage in a excel spreadsheet format. This together with the workspaces for KeRRA, KURA and KeNHA will be used to prepare a consolidated HDM-4 workspace to be used in the preparation of the RSIP.

5 Study Approach and Methodology

5.1 HDM-4 Configuration

Traffic Flow Patterns

The levels of traffic congestion vary with the hour of the day and on different days of the week and year. To take account of this, the number of hours of the year for which different ranges of hourly flows are applicable will be determined from the data that will be collected. To configure traffic flow pattern, the distribution of hourly flows over 8760 hours of the year will be defined for each road use type based on available data from the road agencies.

Speed-Flow and Speed Reduction Factors

The speed-flow model adopted in HDM-4 for motorised transport (MT) is the three-zone model illustrated in Figure 3. Motorised vehicle speeds and operating resources are determined as functions of the characteristics of each type of vehicle and the geometry, surface type and current condition of the road, under both free flow and congested traffic conditions.

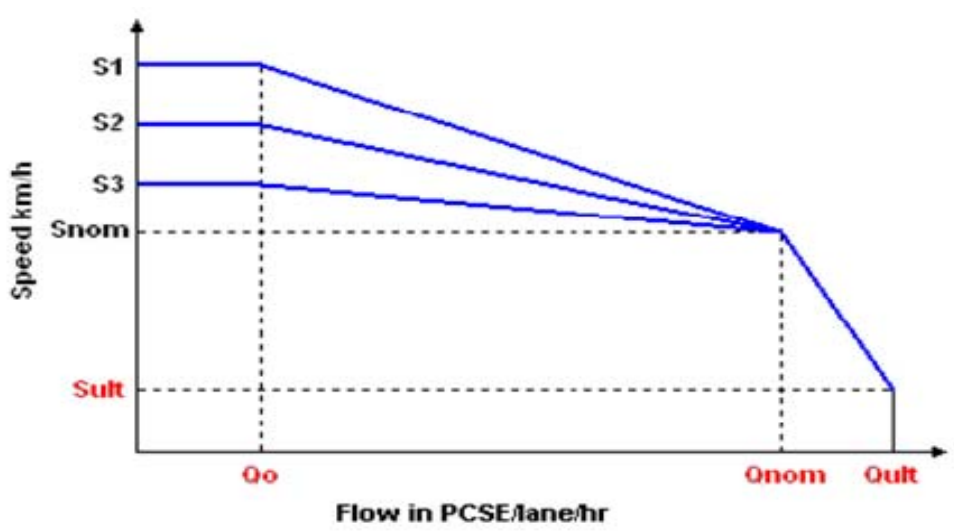


Figure 3: HDM-4 Speed - Flow Model

Using available data provided by the road agencies in Kenya, the speed-flow model will be configured for different road types by defining the following values: Q_o is the flow level below which traffic interactions are negligible in PCSE/h; Q_{nom} is nominal capacity of the road (PCSE/h); Q_{ult} is the ultimate capacity of the road for stable flow (PCSE/h); S_{ult} is speed at the ultimate capacity, also referred to as jam speed (km/h). The following additional notations apply to Figure 3: S_{nom} is speed at the nominal capacity (km/h); S_1 to S_3 are free flow speeds of different vehicle types (km/h); and PCSE is passenger car space equivalents.

For modelling traffic flows and effects on vehicle operating costs (VOC), HDM-4 considers three types of friction:

- (i) Friction to motorized transport arising from roadside activities, XFRI (e.g. different types of land use and encroachment to the road right of way). XFRI value ranges from 0.4 (high friction level) to 1.0 (no friction).

- (ii) Friction to motorized transport due to the presence of non-motorised transport XNMT (e.g. pedestrians, bicycles, animal carts). XNMT value ranges from 0.4 (high friction level) to 1.0 (no friction).
- (iii) Friction to non-motorized transport arising from motorized transport using the road, XMT. Values of XMT also range from 0.4 to 1.0.

To assist the agencies in assigning degree of friction for road sections, indicative photographs will be provided illustrating typical road sections that can be classified in each friction grade (i.e., High, Moderate or Low). This methodology has been successfully applied in other countries; for example, the photographs in Figure 4 were used to grade the road friction on roads in Nigeria and Uganda.

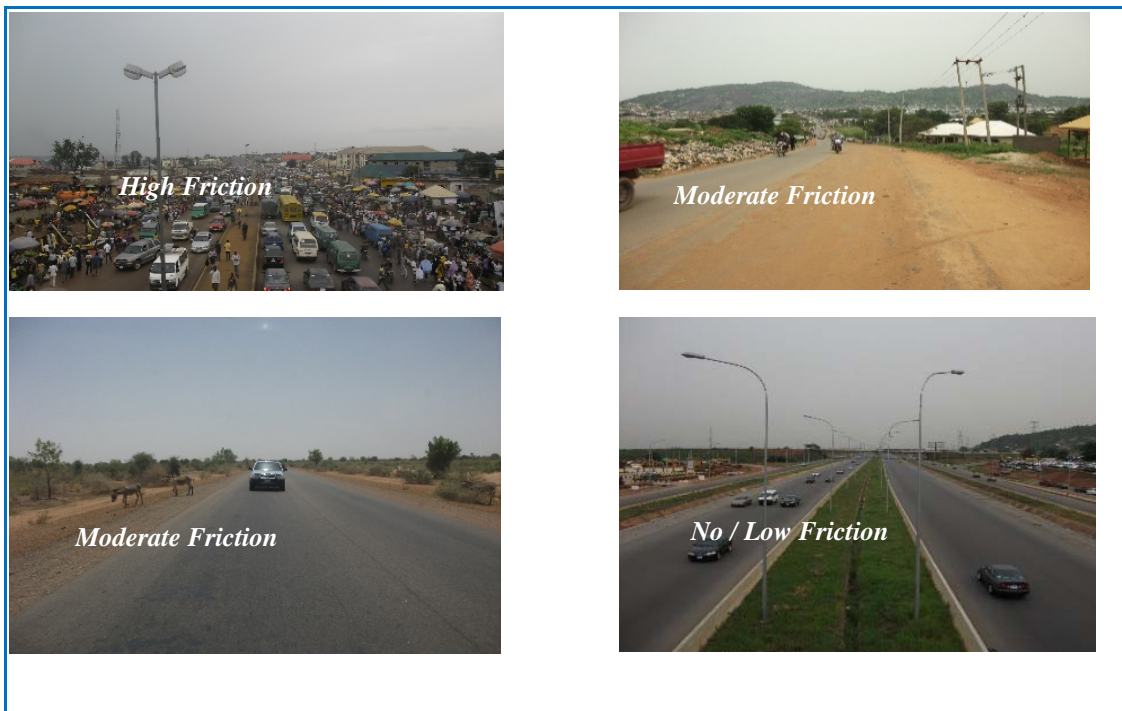


Figure 4: Photographs Showing Different Levels of Friction

Accident Classes, Rates and Costs

Accident rates for road stereotypes will be determined using data from the Kenya Police Service records, the National Transport and Safety Authority (NTSA) and other sources. Accident rates in 'number per 100 million vehicle kilometres' will be determined for the following categories of accidents modelled in HDM-4: fatal accidents; injury; and damage only accidents. Accident rates for each severity vary with parameters like road type, traffic level and flow-pattern, the presence of non-motorized transport, road geometry, and road surface characteristics.

Although it is not easy to attribute monetary values to the losses arising from accidents, estimates of accident costs are essential aid to decision-making in the road safety aspects and investment choices. Costs of road accidents arise from the following areas, TRL (2005):

- Damage to vehicles and other property
- Costs of hospital treatment, police work, administration, etc.
- Loss of life and injury

The first two areas of losses involve material resources and are normally readily defined, even though their values may be uncertain. They can be translated into economic terms without great difficulty. Costs relating to the loss of life and injury are subjective, involving the need to value human life and 'pain, grief and suffering'. The valuing of human life is a difficult and often contentious process. Several methods of valuing human life exist including the gross output, net output, life insurance, court award, value of risk-charge, and implicit public sector valuation. Different accident cost methodologies will be investigated in order to select those that are relevant to the objectives being pursued taking into consideration data availability and quality in Kenya.

Climate Zones

Existing HDM-4 workspaces used by the road agencies in Kenya have input for the Climate Zone. Twelve climate zones have been defined for Kenya based on temperature classification and moisture regime. These need to be reviewed using new data from Kenya Meteorological Department and literature with the aim of rationalizing the number of climate zones relative to the degree of accuracy required by HDM-4 analysis. For each climate zone, the following parameters will be reviewed and if found necessary updated: moisture Index; duration of dry season as a percentage of the year; mean temperature; number of days with temperature greater than 35 degrees Celsius; freeze index; and percentage of time vehicles are driven on wet roads.

Road Network Aggregate Data

The entails defining relationships between high level aggregate data and low level detailed data using the concept of Information Quality Level (IQL), Paterson and Scullion (1990). The IQL concept, depicted in Figure 5, allows data to be structured in ways that suit the needs of different levels of decision making and the variety of effort and sophistication of methods for collecting and processing data.

Configuration of aggregate data will involve the definition of aggregate information for the following: Traffic levels: e.g., low, medium, high; Geometry class: in terms of parameters reflecting horizontal and vertical alignment; Pavement characteristics: structure and strength parameters defined according to pavement surface class; Road condition: ride quality, surface distress and surface texture; and Pavement history: mainly construction quality and pavement age.

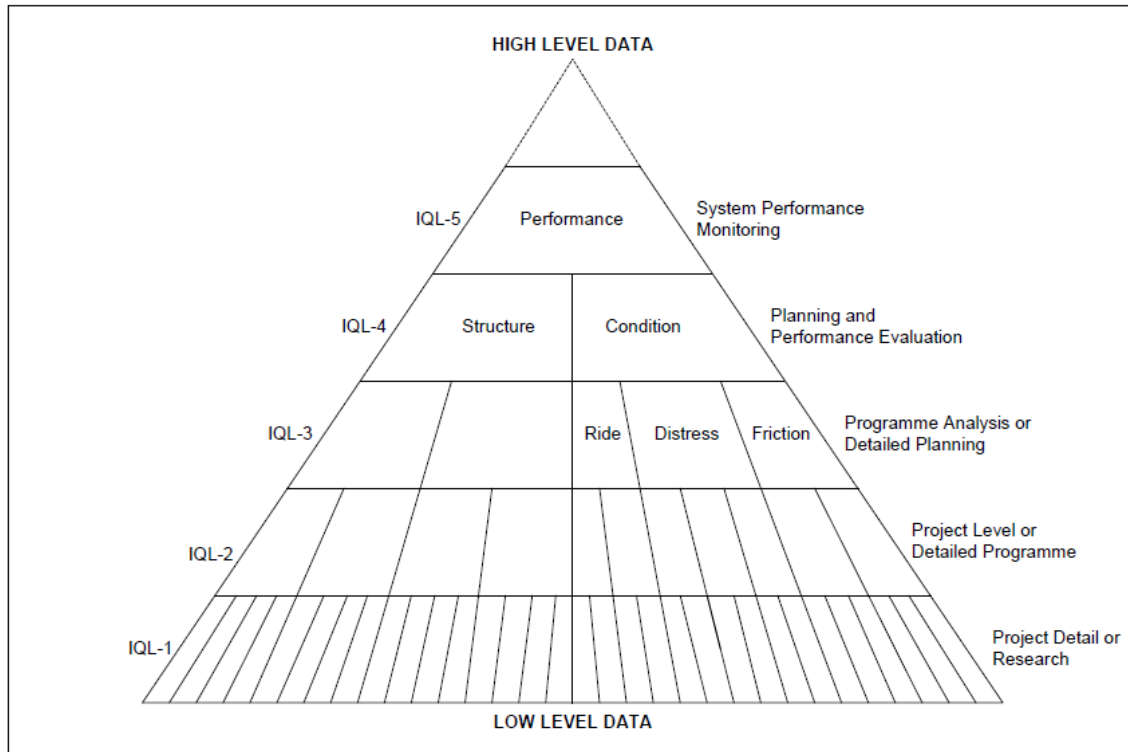


Figure 5: Concept of Information Quality Level

5.2 Calibration of HDM-4 models

Road Deterioration models

Road pavements deteriorate as a consequence of several factors, most notably: traffic volume and loading, pavement design, material types, construction quality, environmental weathering, effect of inadequate drainage systems, and works on utilities. Road deterioration is modelled in terms of cracking, ravelling, potholes, edge-break, rutting, roughness, friction and drainage. Roughness draws together the impacts of all other pavement distresses and maintenance. It is the dominant criterion of pavement performance in relation to both economics and quality of service as it gives most concern to road users.

For each pavement type and each distress type there is a generic model which describes how the pavement deteriorates. The approach for calibrating RD models can be summarised by the steps illustrated by Figure 6.

Work Effects model, Standards and Unit Costs

The approach to calibrate Work Effects models will ensure the effects of works performed on bituminous, unsealed and concrete roads are determined. We will review maintenance history data and for various treatment types, determine the condition of the road pavement before and after treatment. This information will be used to calibrate HDM-4 works effects models for different types of treatments such as new construction or reconstruction, overlay, and reseal amongst others. When a works activity is performed, the immediate effects on road characteristics and road use need to be specified in terms of the following: pavement strength, pavement condition, pavement history, road use patterns, and asset value.

The standard of road construction is dependent on the materials, degree of compliance with design specifications, construction tolerances and the level of site supervision. The key construction defect indicators in HDM-4 are:

- Construction defect indicator for surfacing (CDS), which influences the initiation of cracking and ravelling, and rutting due to plastic deformation
- Construction defect indicator for the road-base (CDB), which influences the formation of potholes
- Relative compaction of the whole pavement (COMP), which affects rutting.

It is important to define these construction defect indicators to depict the general situation in Kenya.

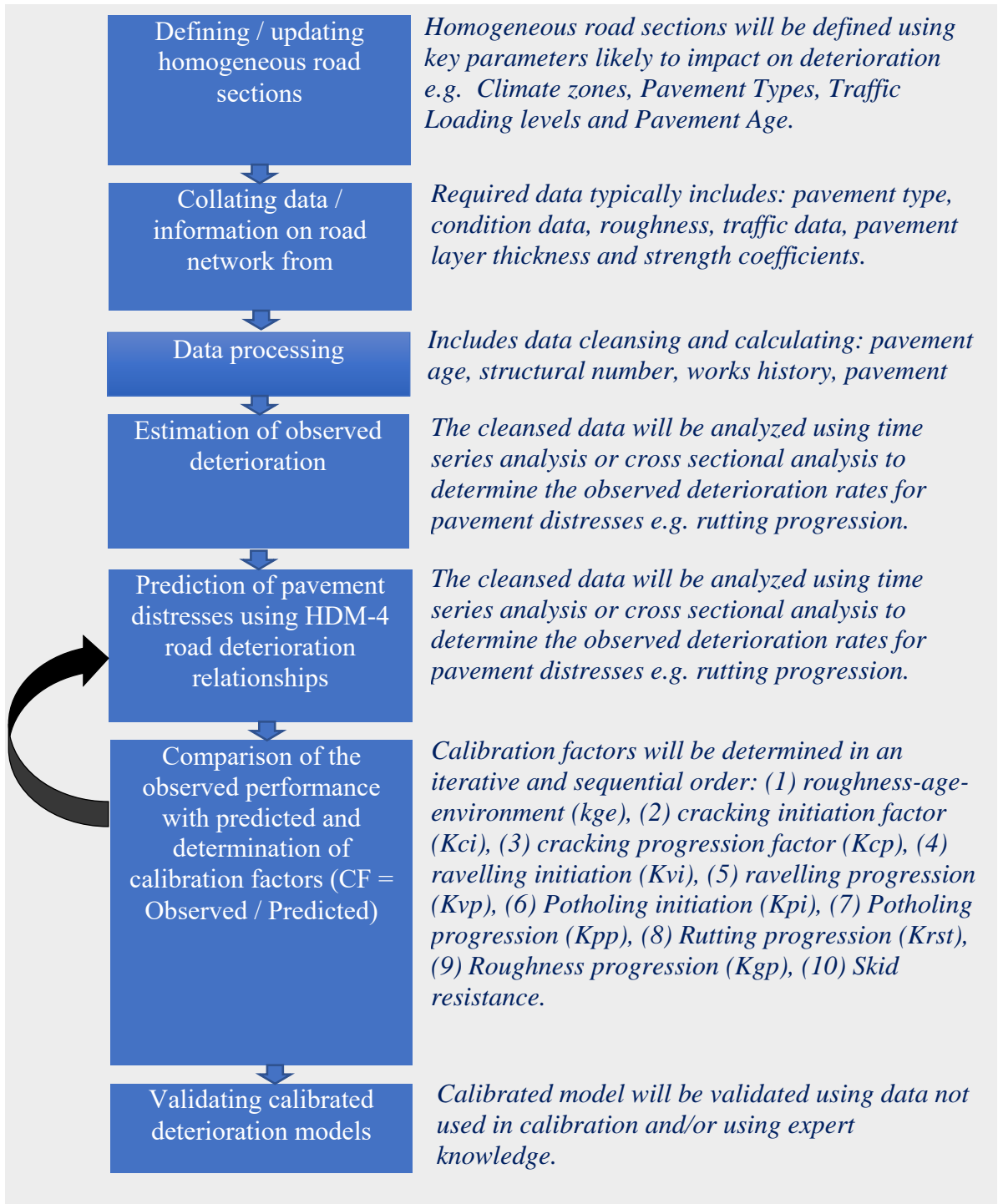


Figure 6: Road Deterioration Calibration Process

Standards refer to the levels of conditions and response that a road administration aims to achieve in relation to functional characteristics of the road network system. The choice of an appropriate standard is based on the road surface class, the characteristics of traffic on the road section, and the general operational practice in the study area based upon engineering, economic and environmental considerations. In HDM-4, a standard is defined by a set of works activities with definite intervention criteria to determine when to carry them out.

In general terms, intervention levels define the minimum level of service that is allowed. Road agency resource needs for road maintenance are expressed in terms of the physical quantities and the monetary costs of works to be undertaken. The annual costs to road agency incurred in the implementation of road works are calculated in economic and/or financial terms depending on the type of analysis being performed. The cost of each works activity need to be updated regularly and considered under the corresponding user-specified budget category (capital, recurrent or special).

Road User Effects (RUE)

The impacts of the road condition, road design standards, and traffic levels on road users are measured in terms of road user costs, and other social and environmental effects. Road user costs comprise vehicle operation costs, costs of travel time, and costs to the economy of road accidents. Vehicle operating costs are obtained by multiplying the various resource quantities by the unit costs or prices. Thus, the annual road user costs (RUC) are calculated for each vehicle type, for each traffic flow period and for each road section alternative. HDM-4 RUE models have been calibrated to conditions in Kenya in a study conducted in 2011. Unit costs of various vehicle resource consumption will be collected in a field survey and used to update the Kenya HDM-4 workspace.

5.3 Vehicle Fleet Data

Equivalent Standard Axle Load Factors (ESALF)

Axle load data from all weighbridges in Kenya will be used to derive equivalent standard axle load factors for the representative vehicles included in Kenya HDM-4 workspace. The approach to the task can be summarized as follows:

1. Review the axle configuration of the representative vehicles used in the current HDM-4 workspace with data from weighbridges and from other sources within Kenya and update if necessary;
2. Analyse the axle load data from weighbridges to establish the severity of overloading particularly on strategic routes used by heavy vehicles and to determine ESALF by vehicle type and region (defined by weighbridge location);
3. Enter the calculated ESALF in HDM-4 workspace for Kenya.

Non-Motorized Transport

Relevant non-motorized transport modes need to be identified and defined in Kenya HDM-4 workspace. It is expected that bicycles, pedestrians and animal carts will be included as NMT modes in the Vehicle Fleet in HDM-4 workspace.

Traffic Growth

As a guide it will good to include traffic growth rates in the Vehicle Fleet. Ideally, growth rates would be inferred from historical records of vehicle-km for traffic in the project corridor. When such records do not exist, however, inferences have to be drawn from: traffic counts; numbers of registered vehicles; fuel sales; GDP growth; GDP per capita and population growth.

5.4 Updated Customized HDM-4 Workspace for Kenya

The outputs from the configuration and calibration tasks described in previous sections will be used to produce an updated customized HDM-4 workspace for analysing road investment choices in Kenya. The customized workspace will contain vehicle fleet characteristics and resource consumption unit costs; traffic growth rates; default unit costs of road works in financial and economic terms; maintenance standards; asset valuation parameters; configuration datasets; model calibration parameters; project analysis case studies; programme analysis case study; and strategy analysis case study.

6 Challenges

The main challenges being encountered in the exercise to configure and calibrate HDM-4 to conditions in Kenya relate to data. Some of the major challenges are presented as follows:

1. Road agencies have been collecting and maintaining data for its road network for some years. This data is being stored in various formats in the agencies' respective databases. It has been particularly difficult not only to retrieve this data from the databases but also to obtain complete historical data sets that can be used to calibrate HDM-4 RD and WE models.
2. Data on the current status of the road network is required in order to configure and calibrate HDM-4 models. This data need to be collected from the field however it is costly and time consuming.
3. A lot of field data is being collected and the processing of this data into suitable formats required as inputs for carrying out HDM-4 configuration and calibration poses a major challenge to the road agencies.
4. Dealing with the issue of missing incomplete or lack of data is also a major challenge being encountered. This is being addressed by applying the IQL concept and using look-up tables of representative road sections.

7 Conclusions

The case study presented in this paper has demonstrated how HDM-4 can be established as a comprehensive decision support tool for use by the road agencies in Kenya. This would enable the road agencies to carry out medium to long-term planning of development and maintenance expenditure and investigate investment choices on Kenya roads. Prior to using HDM-4 in any country, the system should be configured and the relevant prediction models should be calibrated to reflect local conditions. The major challenges being encountered relate to availability of complete data sets, in particular the lack of appropriate time series data on road pavement performance and traffic, for the calibration of road deterioration models.

HDM-4 can be used to determine the effects of various funding levels. Both the strategy and programme analysis tools optimize investment options subject to available budget to minimize total transport costs by considering the costs to the road authority and road users. To that end, HDM-4 provides a good framework for ensuring that funds for maintenance of roads are distributed equitably amongst road authorities, and provide value for money for the taxpayer. From the foregoing, it is clear that there is the need for Kenya to adopt one configured and calibrated HDM-4 workspace in order to improve the accuracy of investment modelling and guide investment decision making in the sector.

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