CALIBRATION OF ROAD INVESTMENT TECHNICAL AND ECONOMIC APPRAISAL MODEL

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***Summary**: The HDM-4 system is a software tool that is used to appraise the technical and economic aspects of road investment projects. It has become widely used as a planning and programming tool for highway expenditure and maintenance standards. Since the model simulates future changes to the road system from current conditions, the reliability of the results is dependent, among the remaining elements, upon how well the predictions of the model fit the real behavior. That is why application of the model involves an important calibration step to local conditions and environment.*

***Key words**: calibration, local conditions, climate, traffic, pavement deterioration*

1. INTRODUCTION

Road management assumes established, documented procedure for organization, coordination and control of all activities and measures that can have the influence on road agency and user costs, and on durability and functionality of roads. Primary aim of management is to realise highest possible benefit from available resources and collected information, and to enable safe, comfortable and economical road transport. This is being enabled by mutually dependent elements of Road Management System (RMS). Planning, design, construction, operation and maintenance are basic functions of a RMS, and these contain numerous sub-systems with very diverse processes. It is possible to claim that RMSs are techno-economical models that should be capable for long-term estimate and dimension of all, frequently contradictory, requests of road stakeholders (those who manage the network with limited resources, those who use the roads and, with all legitimate rights, expect necessary level of safety and comfort, and community with its aims of preserving invested capital and reduction of its operation costs).

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Although numerous systems and management models exist in the world, not even one of them can be directly and easily adopted and applied within the conditions of particular country, having diverse technical, economic, environmental and social circumstances. Experience of different countries imply that probably the first lecture to be learned from else's experience is that there is no lecture i.e. recipe, but only the general framework for establishment and operation of the system. The truth is that one management system is the concrete answer on exact problem of one region or one state road network, and it is clear that each model has to be calibrated to specific local conditions and environment.

2. HIGHWAY DEVELOPMENT AND MANAGEMENT MODEL

The HDM-4 (Highway Development and Management) system is a software tool (Figure 1) that is used to appraise the technical and economic aspects of road investment projects by evaluating policies, standards and programs of road construction and maintenance. It can be basically classified as a pavement management tool, and is the recommended choice of the World Bank and other International Financing Institutions (IFIs) for technical and economic analysis of projects funded by these institutions.

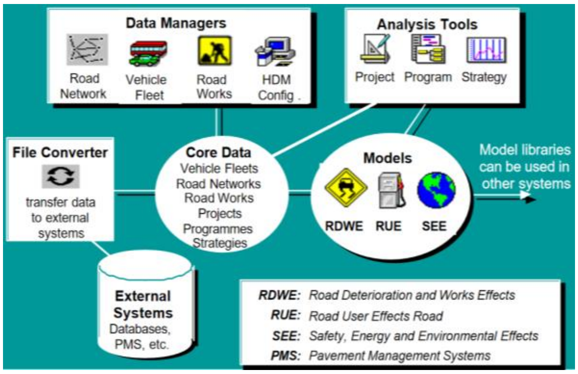

Figure 1. HDM-4 software system architecture [2]

HDM-4 simulates physical and economic conditions over the period of analysis, usually a life cycle, for a series of construction and maintenance alternatives and scenarios, either for a given road project on a specific alignment or for groups of links on an entire network. It estimates road user benefits, infrastructure costs and externalities, including accidents, energy consumption and emissions for alternative investment strategies year-by-year for up to 40 years, discounting the future costs, if desired, at different specified discount rates, to search for the alternative with the lowest discounted total cost. Internal rates of return, net present values or first year benefits can also be determined by the model.

In order to make a comparison of alternative construction and maintenance strategies, detailed specifications of construction programs, design standards and maintenance alternatives are needed, together with unit costs, forecasted traffic volumes, and environmental conditions. The model simulates, for each road link, year-by-year, the pavement condition and resources used for maintenance under each strategy, as well as the vehicle speeds and physical resources consumed by vehicle operation.

Since the model simulates future changes to the road system from current conditions, the reliability of the results is dependent upon two primary considerations [1]:

- how well the data provided to the model represent the reality of current conditions and influencing factors, in the terms understood by the model;
- 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:

- Data input: a correct interpretation of the data requirements, and achieving a quality of input data that is appropriate to the desired reliability of results;
- Calibration of outputs: adjusting the model parameters to enhance how well the forecast and output represent the changes and influences over time and under various interventions.

The various models given in HDM-4 need to be calibrated for local traffic and environmental conditions. Reliable calibration factors are useful for budgeting purpose and this avoids under- or overestimates of the budget. Calibration of the HDM-4 environment to local conditions requires establishment of the following calibration parameters:

- Free flow speed: HDM-4 model calculates operation speed on the basis of traffic and road characteristics. Driver’s influence is being taken onto account through the parameter called “desired speed” established by measuring the speed in a free flow;
- Hourly flow: Hourly traffic distribution describes distribution of hourly traffic flow during the year and is being used for definition of periods of different traffic volume levels. Influence of daily variation of traffic load on traffic flow is being taken into account by this way. Hourly distribution of traffic flow is defined by number of hours during the year where traffic volume reaches certain percent of Annual Average Daily Traffic (AADT);
- Speed-flow function: HDM-4 model adapts vehicle speed to traffic flow and road condition. Establishment of speed-flow function for different types of roads requires extensive studies;
- Vehicle fleet: Vehicle Operating Costs (VOCs) are being established by calculating quantities of used resources and vehicle speeds, and then multiplying them with unit price of resources to get total operating costs and travel times for each type of vehicle. Calibration procedure considers selection of representative vehicle types and establishment of their technical and economic characteristics;
- Axle load: Pavement deterioration process significantly depends on distribution of axles and loads. HDM-4 model performs prognosis of pavement deterioration taking into account the axle loads, above other parameters;
- Climate: Climate parameters are being used for establishment of pavement deterioration during time;
- Pavement deterioration: Pavement deterioration calibration module enables definition of a range of calibration coefficients for each section and for different pavement types. Pavement damage initiation and progress can be calibrated to local conditions with these coefficients.

3. LEVELS OF CALIBRATION

HDM-4 calibration can be performed at three levels, which involve low, moderate and major levels of effort and resources, as follows [1]:

- Level 1-Basic application: This calibration level is required for all HDM-4 analyses and addresses most critical parameters, while assuming that most of the HDM-4 default values are appropriate. It is mainly based on secondary sources and is being done through "desk" studies with best estimates and minimal field surveys;
- Level 2-Verification: Within this level, measurements are being made to verify and adjust predictions to local conditions. It requires moderate data collection and moderate precision. Adjustments are entered as input data, and typically without any software changes;
- Level 3-Adaptation: This level comprises structured research (medium-term) and advanced data collection (long-term). With this approach, trends and interactions are being evaluated by observing performance over medium- and long-term period. Major field surveys are being performed to re-quantify relationships. This may lead to alternative locally derived relationships/models.

In terms of effort, these three levels can be viewed as weeks, months and years. An analyst should be able to undertake a Level 1 calibration in about one week. For a Level 2 calibration there is an increase in the amount of effort required so it will take at least a month. Level 3 calibration requires a long-term commitment to basic data collection so its extend spans for a year or more.

3.1. Calibration of Traffic and Climate Parameters

Calibration parameters related to traffic volume and vehicle speed are obtained through analysis of available traffic data (normally including volumes and flow composition) and data collected through specific studies. Update intervals of three to five years for traffic data are sufficient to obtain relevant parameters for calibration and to reflect changes in national vehicle fleet, increase/decrease of traffic load and drivers' behavior.
Climate characteristics are not changed very often and updates of climate parameters can be based on time interval not shorter than five years, but not longer than ten years. Collection of climate data is the least costly of all monitoring activities. For example, the weather and climate data recorded on airports, national weather stations and local weather news channels are usually available from the Internet. In most countries, the climate data are available in electronic and published documents from meteorological departments/offices for all of their climate regions. For the future updates of the climate parameters, a good cooperation with relevant institutions has to be established and maintained.

3.2. Calibration of Pavement Deterioration Models

Pavement deterioration models present the most important part of a Pavement Management System (PMS). Pavement deterioration model expresses a function of distress level due to traffic, as well as environmental factors in sense of structural response (strains and deformations) of pavement, repeated traffic load, pavement composition, road geometry, and subgrade temperature and moisture. Defining and calibration of pavement deterioration models depending on combined impacts of traffic load, local climate conditions, material characteristics, as well as historical data of road construction and maintenance, could be achieved through establishment of empirical model of pavement mechanical behavior on the basis of multi-year investigations and observations/monitoring of pavement condition indicators on test sections Pavement deterioration model determined as a function of local, specific conditions, has important role in connecting construction and maintenance standards as well as road user costs through established mathematical relations of pavement deterioration. HDM-4 includes relationships for modelling road deterioration and road works effects. For each pavement type and each distress type there is a generic empirical regression model which describes how the pavement deteriorates [1, 3].

These are used for the purpose of predicting annual road condition and for evaluating road works strategies. The relationships should link standards and costs for road construction and maintenance to road user costs through road user cost models. Road deterioration is predicted through eight separate distress modes, namely: cracking, raveling, potholing, edge-break, rutting, roughness, texture depth and skid resistance.

These distresses are analyzed through following categories:

- Surface distresses: This category comprises cracking, raveling, potholing and edge-break. The first three distress modes are characterized by two phases referred to as initiation and progression. The initiation phase is the period before surfacing distress of a given mode or severity develops. The progression phase refers to the period during which the area and severity of distress increases. Edge-break is modeled only through its continuous progression;
- Structural/deformation distresses: This category comprises rutting and roughness. Deformation distress modes are continuous and represented only by progression equations. Being partly dependent upon the surfacing distress, they are computed after the change of surfacing distress in the analysis year has been calculated;
- Surface texture distresses: This category comprises texture depth and skid resistance. Surface texture distress modes are continuous and, like deformation distress modes, they are modeled only through their progression.

Each of the mentioned pavement distress types has to be modeled within HDM-4 model and represented with adequate equations containing “calibration factors”, enabling adaptation and calibration of pavement deterioration models according to local conditions.

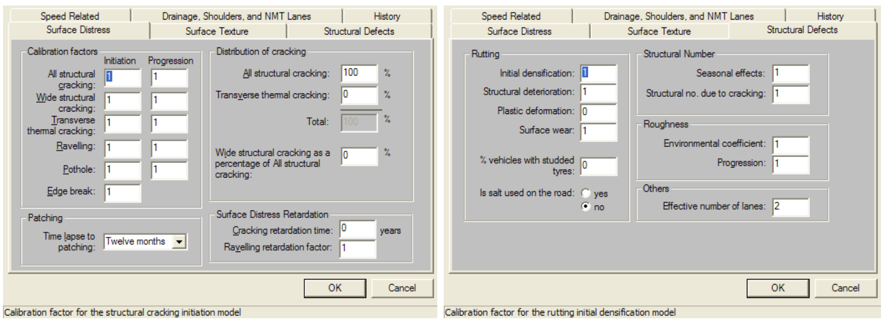

Figure 2. Default coefficient values for pavement surface and structural distresses

To calibrate a pavement deterioration model, it is necessary to have a group of distress data that serve to represent the real performance curve; preferably the data represent a relatively long period of time.

The process of calibration consists of determining which adjustment factors achieve the best agreement between the model's prediction and the field data. Figure 2. shows default values of calibration factors for pavement surface distress models and structural pavement distress models in HDM-4 model.

4. APPROACH TO HDM-4 CALIBRATION

Calibration of road deterioration models according to local conditions can be performed through multi-year monitoring of pavement condition on proposed test sections, based on predefined plan and program of periodical surveys through parametric regression data analysis [5, 14].

Calibration of pavement deterioration requires selection of 10 to 20 test sections (only paved sections to be considered), which represent road network regarding features, condition and traffic. It is common that two or more series of measurements should be performed on the test sections in the period not shorter than three years.

With every additional measurement of pavement condition indicators, the "initial" pavement performance models would be revised and verified according to increased database of pavement condition data collected from test section, resulting in improved pavement performance models, depending of local conditions. In order to verify "initial" road deterioration models, it is necessary to perform regular surveys and monitor pavement performance indicators on selected representative test sections on the road network. Development of road deterioration models should be continuous activity, with the goal for constant improvement of model characteristics and better use of available data.

Test sections should be selected for periodic inspections/observations that have to be performed twice a year during 10-years calibration period. Based on inspection results during the first five years, the preliminary pavement performance models may be developed. This represents minimal statistical sample for results analysis (5-year period during which observations on selected test sections will be performed). Period of the following five years is considered as verification of proposed performance models for individual distresses through continued inspections.

This proposed approach corresponds to Level 3-Adaptation model of calibration. Collected data should be stored in separate database on road inspections, e.g. database on road deterioration for test sections, which will allow statistical data analysis in certain time periods.It is necessary to have reliable data for selection of test sections.

Therefore, it is necessary to define parameters and criteria for identification of test sections based on which the matrix of test sections will be formed. On the other hand, it is also possible to utilize the data from main pavement surveys (3-year interval) for the same test sections, and on the basis of at least three consecutive measurements to obtain calibration factors for pavement deterioration model.

This alternative approach, with less time series of data, is compatible with Level 2-Verification model of calibration.

4.1. Selection of Test Sections

Test sections should represent the road network based on pavement type, material characteristics and cumulative traffic load, as well as climate characteristics in certain zones. Having in mind difficulties that are expected in identification of test sections, the following Table 1. lists the proposed parameters for selection of test sections [5, 14].

Table 1. Parameters for selection of test sections

parameter	characterization	description
pavement structure	original pavement	asphalt concrete on bituminous base
		asphalt concrete on cement-stabilized base
	overlay	asphalt concrete on asphalt concrete
		asphalt concrete on bituminous base
		bituminous base on bituminous base
AADT	medium	AADT < 3,000 veh/day
	heavy	AADT > 3,000 veh/day
MAP (Mean Annual Precipitation)	low (dry climate)	MAP < 800 mm/year
	high (wet climate)	MAP > 800 mm/year
frost penetration	low	< 50 cm
	high	> 50 cm
pavement condition	good	< 10% distressed area
	fair/poor	> 10% distressed area
pavement age	new	< 5 years
	old	> 5 years
level of maintenance	regular	
	intensified	
	no maintenance	

During identification of test sections in the field, the following criteria should be satisfied [5, 14]:

a) Test sections should be minimum 0.5 km long (recommended 1 km). The length of test section of 1 km is recommended for roughness and deflection measurements and visual distresses survey (due to larger uniformity and validity of section, with larger length local events are eliminated);
b) Flexible pavement, being predominant on modern roads, should be on test sections;
c) Test section should be on straight stretch of road regarding horizontal and vertical curvature because of uniform drainage conditions for all test sections;
d) Test sections should not be in the vicinity of intersections or local roads because of traffic distribution and proper recording of traffic loading. Therefore, it is recommended that test sections should be located in the vicinity of automated traffic counter (with classification);

e) Test sections should not be located in urban or suburban areas, i.e. in areas where there are buildings on both sides of road, as well as in urban and suburban areas (due to sewage system and different conditions of traffic flow);
f) Test sections in cutting should be avoided. Test sections should be on embankment of maximum height of 1.5 m. Test sections on higher embankment should be considered only in exceptional cases, if drainage conditions of surface water do not differ significantly;
g) It is necessary to have historical data on test sections construction (for example: year of construction, geotechnical data, traffic flow composition, details on overlays /if these were performed/, year of latest overlay and details, previous investigations /as much as possible/, road maintenance techniques used, etc.);
h) Test sections should be uniform in longitudinal and cross profile in sense of geology, subgrade, embankment height, drainage conditions, pavement condition, as much as possible;
i) Test sections should be selected with different traffic loading regarding traffic volume and traffic composition;
j) Test sections should be in plain terrain with maximum longitudinal grade of 4%, if possible.

To select a group of roads with sufficient characteristics, the first step is to create a matrix that, through a combination of the distinct levels of four global variables - traffic, pavement age (calculated from the date of construction or most recent rehabilitation), dominant climatic conditions and structural capacity - allows one to define the different road categories that comprise the experiment factorial. An effort has to be made to include the largest possible number of homogeneous road sections with the greatest possible difference in age in order to reconstitute performance curves with the greatest level of representation over time. A total of 15-20 sections for paved roads constitute an adequate sample size for most conversions. The total length of sections should be at least 20 km for each pavement type (i.e. bituminous paved, rigid paved). In case the calibration is also required for unpaved roads, i.e. if the significant portion of unpaved roads is being managed through the agency, the sample should contain some 10-15 sections, totaling 20 km in length.

4.2. Periodic Monitoring of Pavement Performance Indicators

Periodic monitoring of pavement performance indicators for the calibration purpose should be planned with half-year intervals and should be performed in April/May and October/November every year during five years. Periodic monitoring (measurements) should contain the following parameters [5, 14]: pavement distresses; pavement roughness; pavement deflections; skid resistance and texture depth; changes in pavement transverse profile (rutting); subgrade moisture; frost depth; traffic counts with classification; axle load survey; and, with additional data (meteorological data, etc.), should provide a good information basis for verification/improvement of road deterioration models.

5. CONCLUSION

Experience shows that application of RMS on complete road network provides the possibility to establish long-term consequences of the adopted policy(ies). One of the possible modes to decide on action to be implemented relies on decision making models developed by simple comparison of observed, current condition and pre-determined standards. More sophisticated systems include theoretically based forecasts of the future performance resulting from previous investigations and either probabilistic or deterministic methods. These are based on the dynamic treatment of roads as civil engineering structures, and, by application of various probabilistic or deterministic models, they forecast road damage level, necessary works and related financial resources. 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. Moreover, if calibration is not carried out, the actual pavement deterioration trend and the HDM-4 predicted deterioration may show large differences. Thus, inadequate local calibrations can lead to an under- or overestimated budget for highway expenditure. The major challenges being encountered relate to availability of complete data sets for the calibration of road deterioration models.
Usually, loan support by the IFIs is being used as a tool to establish road inventory and initial condition, as well as the database, while sustainability is never secured. Moreover, planning and programming exercise is normally being done through the Level 1 calibration and establishment of the “initial” pavement deterioration models, while further steps, including continuous monitoring and improvement of initially calibrated deterioration models, are not being done.
Presented approach to calibration can be suitable for most of countries relying on the IFIs support, especially in the surrounding region throughout which the HDM-4 has been extensively used for the past several decades, and where most of the road agencies or private consultants are in possession of contemporary equipment for data collection and tracking of pavement performance.

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KALIBRACIJA MODELA ZA TEHNIČKU I EKONOMSKU PROCENU PUTNIH INVESTICIJA

Rezime: *HDM-4 je programska alatka koja se koristi za procenu tehničkih i ekonomskih aspekata putnih investicija. Rasprostranjena je kao alat za planiranje i programiranje ulaganja u putnu mrežu i utvrđivanje standarda održavanja. Pošto model simulira buduće promene putne mreže u odnosu na postojeće stanje, pouzdanost rezultata je, između ostalih elemenata, zavisna od toga koliko modelska predviđanja odgovaraju stvarnom ponašanju. Zbog toga primena modela uključuje važan korak kalibracije u odnosu na lokalne uslove i okruženje.*

Ključne reči: *kalibracija, lokalni uslovi, klima, saobraćaj, propadanje kolovoza*