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Introduction

This paper describes the HDM-4 version 2.05 case studies developed by Rodrigo Archondo-Callao, Senior Highway Engineer, World Bank, for use on HDM-4 training courses. The case studies were developed for HDM-4 Version 2.05 and attempt to exemplify the different applications of the model and present some author’s suggestions for better use the software.

HDMGlobal Case Studies

When you install HDM-4 and open it, you get the following screen that shows the case studies developed by HDMGlobal and that are included on the HDM-4 CD. You should refer to Volume 2 of the HDM-4 documentation for explanation about the structure of these case studies.

Note that these HDMGlobal case studies are stored during the HDM-4 installation at the C:\Program Files\HDM-4 Version 2\Case Studies\Eng Windows folder and all the contents of the case studies are stored on two files (objects.dat and objects.idx) that are called HDM-4 workspace. Upon installing HDM-4, you have three options: (i) work with the HDM4Global cases studies, modifying them if needed; (ii) create a new HDM-4 workspace and enter all new configuration and data; or (iii) open and modify another HDM-4 workspace created by somebody else. In this paper, we will be working with an HDM-4 workspace created by the World Bank.

Opening World Bank HDM-4 Workspace

To work with the World Bank case studies, perform the following steps:

a) Uncompress the case study files (objects.dat and objects.idx) supplied by the World Bank and place them at the following suggested Windows folder.
C:\HDM-4 v2.05 WB Case Studies 1.0

Note that if needed you can change the Windows folder location and you have to be aware that the names of the objects.dat and objects.idx files that contain a given HDM-4 workspace can not be changed. Therefore, on your hard drive you can have many HDM-4 workspaces (case studies or projects) that are located on different Windows folders, but with the same file names.

b) Open the World Bank workspace by first selecting at the main menu “Workspace” and then “Open Workspace...”. You will then locate the windows folder where you have placed the supplied objects.dat and objects.idx files and then highlight the objects.dat file and press “Open”.

If you get the following message, press “Yes” to continue.

HDM-4 Workspace Structure

Once you open the workspace, you will get the screen below. Note that the first line indicates the Windows folder where the objects.dat and object.idx files for this workspace are located. The workspace is composed of the following input areas:

a) Configuration, where you configure the workspace to your country conditions.

b) Vehicle Fleets, where you define the characteristics of one or a series of vehicle fleets.

c) Road Networks, where you define the characteristics of one or a series of road networks.

d) Work Standards, where you define the characteristics of a series of road work standards.

If you create a new workspace, you will enter your input data at following that sequence. One you have defined all the input data, you have three possible evaluation options: a) Projects, b) Programmes, or c) Strategies. All evaluation options use the input data defined previously.
If you open one of these input areas, pressing the + box, you will be able to view the options or inputs defined under this area. For example, if you open the configuration area you will get the following screen showing the configuration options. Note that the options and inputs of HDM-4 resemble Windows folders but they are not Windows folder, they are components of the workspace stored at the object.dat and object.idx files.

Configuration

At the configuration input area, for your country, you (i) define a series of valid options for traffic flow patterns, speed flow types, accident classes, and currencies; (ii) define default values for different aggregate data; and (iii) define valid calibration parameters and road deterioration calibration sets. For example, the following was defined under configuration.
Traffic Flow Pattern

Here you can create a new pattern, delete a pattern or edit a previously defined pattern. To create a new pattern, highlight the Traffic Flow Pattern title and press "New", select Traffic Flow Pattern and enter the new pattern’s name. To delete a Traffic Flow Pattern, highlight a Traffic Flow Pattern and press "Delete". To edit Traffic Flow Pattern, highlight a Traffic Flow Pattern name and double click on it. For example for the Inter-urban pattern, you will get the following screen.

Here, for example for an inter-urban road in your country, you first want to collect default values supplied by HDM-4 and then modify the default values if you have data available that allows you to modify the default values. You obtain default values by selecting a road use from the pick list. You modify the default values, by editing the default numbers on the screen. On these case studies, default values were obtained for Inter-urban, Commuter and
Seasonal Roads. Inter-urban roads have a more even distribution of the annual traffic over the days of the year and over the hours of the day. Commuter roads have a higher concentration of traffic during some hour of the day. Seasonal roads have a very high concentration of traffic during some seasonal days.

**Speed Flow Type**

Here you can create new, delete or edit a speed flow type similar to the traffic flow pattern. For example, for a Two Lane road, you will get the following default values. You obtain default values by selecting a road use from the pick list. You modify the default values, by editing the default numbers on the screen. On these case studies, default values were obtained for Two Lane, Wide Two Lane and Four Lane roads.

**Accident Class**

Here you can create new, delete or edit an accident class similar to the traffic flow pattern. In this case, there are no default values; therefore, if you want to include accident benefits on your evaluation, you have to provide the accident rates for different road classes in the country. On these case studies, sample values were provided for Two Lane, Wide Two Lane and Four Lane roads. Note that these accident rates are not global default values or accident rates for a particular country; they are illustrative numbers. For your country, you could define accident rates for different road classes. For example, two lane without shoulders, two lane with narrow shoulders, two lane with wide shoulders, etc.
Climate Zone

Here you can create new, delete or edit a climate zones similar to the traffic flow pattern. For example, for the “North Region” climate, you will get the following default values considering that this region is on a sub-humid/tropical-hot environment. You obtain default values by selecting a moisture classification and a temperature classification from the two pick lists. You modify the default values, by editing the default numbers on the screen. On these case studies, default values were obtained for illustrative purposes for a “North Region” and a “South Region” (Sub-humid/Tropical environment). On your country, you could define the climate for other different regions. For example: costal, mountainous, etc.

Currencies

Here you can add, delete or edit a name and symbol of a currency to be used on the evaluation. In this case, double click on the Currency label. Note that here you define only valid currency names. When defining a project, program or strategy, you will define the conversion factors from one currency to another.
Section Aggregate Data and Tables

At the section aggregate data, you define the characteristics of aggregate parameters related to the condition and traffic of the roads to be evaluated. For example, you define the corresponding Average Annual Daily Traffic (AADT) for “Low Traffic” for your country. HDM-4 supplies default values for all the aggregate parameter given below.

Here you can add, edit, rename the descriptors for each parameter and you can edit the related tables that contain the default values for each descriptor. For example, for Traffic Volume, we have the following default values per traffic band and surface class. These traffic values are country specific; therefore, you should change them to match your country situation. Note that because traffic is important you could improve the table by defining for example five traffic classes (Very Low/Low/Medium/High/Very High).

For geometry we have the following. These values are also country specific. Note that you could simplify the table by defining for example just three terrain classes (Flat/Hilly/Mountainous).

For ride quality we have the following roughness default values. These default values are applicable to most developing countries; therefore; most
HDM-4 user will not need to change them. Nevertheless, the default values could not be applicable to some countries where road construction quality and materials quality are weak. The same applies to the construction quality, structural adequacy, surface condition, and surface texture parameters.

The section aggregate tables present the same information of the section aggregate data in a different tabular format. You can also edit the default values in this format.

Workspace Calibration Parameters

Here you can edit some calibration parameters if you have done a calibration study. Most users will not change these parameters.
RD Calibration Sets

Here you define a set of calibration parameters for the road deterioration of each surface type (Bituminous, Concrete and Unsealed). For each surface type, you add new calibration items and define the corresponding calibration parameters. On this workspace, for bituminous roads, eight calibration items were defined; one for each possible pavement type (combination of two surface types and four base types), containing the default calibration parameters supplied with HDM-4. These eight items represent a situation on running the model without any calibration of the road deterioration models. For concrete roads, a sample calibration item was defined for a JPCP with dowels and for unsealed roads, sample calibration items were defined for gravel roads, all with HDM-4 default values.
Vehicle Fleets

Once you have configured the workspace, you define one or more vehicle fleets. To create a vehicle fleet, highlight the Vehicle Fleet label and press New. To edit a vehicle fleet, highlight the vehicle fleet name and double click. On this workspace, only one vehicle fleet was defined as shown below representing illustrative vehicles on developing countries.

If you double click on the vehicle fleet name you will be able to view and edit the contents of the vehicle fleet. In these case studies, ten motorized vehicle types were defined; all with a vehicle name labeled starting with a number so that they appear in logical order and not in alphabetical order. To view the contents of vehicle type, highlight the vehicle type line and double click.

The screen below shows the vehicle called “09. Bus Medium”. The definition tab presents global identification parameters.
The Basic Characteristics tab presents basic vehicle physical, tires, utilization and loading characteristics. HDM-4 provides default values for all these parameters, which were adopted on these case studies.

The Economic Unit Costs tab presents the input requirements required to quantify unit road user costs for each vehicle type. HDM-4 does not provide default values for these inputs because they are country specific. The values on the case studies are illustrative values for developing countries.

At the vehicle fleet main menu screen, by pressing the corresponding buttons at the bottom of the screen, you also define (i) the vehicle fleet description and the currency of the economic unit costs; and (ii) traffic growth sets. The defined traffic growth sets are given below that correspond to annual traffic growth rates of 0%, 3%, 6% and 9% for all vehicles during the evaluation period.
This is the simplest way of defining traffic growth rates; on a more complex scenario, HDM-4 could be setup so that traffic growth rates vary by vehicle type and along the evaluation period. This is done adding new periods to the traffic growth rates.

**Road Networks**

Once you have defined the vehicle fleets and the corresponding traffic growth rates, you define one or more road networks. To create a road network, highlight the Road Networks label and press New. To edit a road network, highlight the road network name and double click. On this workspace, four road networks were defined as shown below for illustrative purposes. The “North Region Project Roads” stores roads related to the project level case studies. The “North Region Road Homogeneous Sections” stores road sections used on the program analysis case studies. The “North Region Strategy Road Classes (2X5X5)” and “South Region Strategy Road Classes (2X53X3)” are used on the strategy analysis case studies.
If you double click on the road network name you will be able to view and edit the contents of the road network. On the “North Region Project Roads” road network, a series of roads were defined. These roads represent homogeneous road sections in terms of traffic and condition with a given origin and destination. To view the characteristics of a given road, highlight the road line and double click.

The screen below shows the “Paving Project (300/Fair)” road that represents a gravel road with 300 AADT in fair condition. Here you characterize the current condition of the road by entering the required inputs at the different tabs.
On the “North Region Road Homogeneous Sections” road network, a series of paved homogeneous road section were defined that will be evaluated under the Programme Analysis module, under budget constraints.

On the “North Region Strategy Road Classes (2X5X5)” road network, fifty road classes were defined that represent a combination of two possible surface types, five possible traffic levels and five possible road condition categories. Each road class represents many road sections with the same characteristics in terms of surface type, traffic and road condition that belong to an overall road network. These road classes will be evaluated under the Strategic Analysis module, under budget constraints.
Work Standards

Here you define and maintain a database of possible maintenance standards, improvement standards and new construction sections.

Maintenance Standards

On this workspace there are about 41 maintenance standards, each representing a possible policy of the road agency in terms of maintenance works types and maintenance works frequencies. Each standard has a unique name that in this case has the following structure for maintenance standards for bituminous roads:

- \( R \) for apply routine maintenance
- \( +P \) for plus apply patching
- \( +xxxxxx \) for plus apply xxxxxx
Different HDM-4 users will name their standard on a different way; therefore each HDM-4 case study could look totally different.

If you double click on the “R+P+40mm Overlay at 4.0IRI” standard, you get the following screen. Here one can see that routine maintenance (Miscellaneous and Drainage work items), patching, and 40mm Overlay triggered at a roughness of 4.0 IRI will be done while this standard is active. Each selected work type has a different intervention definition.

If you double click on Miscellaneous and open the Intervention tab, you will see that miscellaneous works (for example, repairing horizontal and vertical signs) will be done every year.
Drainage works (for example, cutting the grass and cleaning the ditches) will also be done every year.

Patching will not be scheduled every year but will have a condition responsive trigger. It will be done when the number of potholes is greater than one per kilometer, in effect patching all potholes.

The 40mm Overlay will be executed when the road roughness reaches 4.0 IRI, m/km.

Another way of setting up when capital works will be done is illustrated at the “R+P+80mm Overlay in 2007” standard. In this case, one wants to schedule an 80mm Overlay in 2007 and after this initial overlay is executed, one want to follow up with a condition responsive 40mm overlay when roughness reaches 4.0 IRI that will maintain a road in good/fair condition.
The “2007 80mm Overlay” work item executes the overlay in 2007.

The “Next 40mm Overlay” work item, executes the 40mm Overlay at 4.0 IRI, m/km, but also ensures that this overlay will not be done before 2013 to avoid having two capital road works executed next to each other, with a minimum 6 year interval.

The workspace has a series of maintenance standard for unsealed roads that have names staring with the label “Unpaved” and represent different levels of grading. They are composed of the following work items: (i) routine maintenance (miscellaneous) done every year; (ii) regravelling done when the gravel thickness reaches 50mm; and (iii) grading at different grading intervals in days (365, 182, 90, 60 and 30 days).
The workspace has a sample maintenance standard for rigid pavements that has a name starting with the label “Rigid”. It is composed of the following work items: (i) routine maintenance (miscellaneous) done every year; (ii) slab replacement done when the total carriageway cracked area is more than 5%; and (iii) joint sealing done every 10 years.

**Improvement Standards**

Improvement standards are defined to characterize pavement reconstruction, upgrading, partial widening, lane addition and realignment works. On this workspace there are about 10 improvement standards, each representing a possible improvement option. For example, the “Project 1 ...” improvement standards are timing paving option for a gravel road; the “Project 3 ...” improvement standards are widening option for a congested road; and the “Project 5 ...” improvement standards are surface type paving options for a gravel road.
Each improvement standard is characterized by different type of information that is classified in different tabs; therefore, if you change an improvement type at the General tab, the information required on the other tabs will change accordingly to the new improvement type. The General tab defines the name of the standard, the existing surface type, the improvement type and the construction duration.

The Design tab defines the new design attributes of the road.

The Intervention tab defines when the improvement work will be done. The Costs tab defines the unit construction cost and the salvage value. The Construction tab defines construction calibration parameters. The Pavement
type defines the new pavement characteristics. The Geometry tab defines the new geometry characteristics. The Effects tab defines the condition after works. The Asset Valuation tab defines the asset valuation parameters.

**New Construction Sections**

Here one defines the characteristics of new sections that are used on the evaluation of bypasses. The evaluation of bypasses is done when one selects “Analyze by Project” at the General tab when defining the project details of a project.

The evaluation of bypasses is out of the scope of these case studies.

**Default Works Currency, Costs and Energy Consumption**

Here one selects the currency being used to define the maintenance and improvement unit costs, one enters optional default economic and financial unit costs of road works per road work type, one defines the budget heading of each road work (Recurrent or Capital); and one enters the energy usage per road work.
Working with a Workspace

If you create a new workspace, you will need to first define your configuration, vehicle fleets, road networks and standards and then you will define your study (project, programme, or strategy). To review a workspace created by somebody else you have two options: (i) review first the configuration, vehicle fleets, road networks, and standards and then review a project, programme or strategy; or (ii) go directly to a project, programme, or strategy and from within one of these access the corresponding road network, vehicle fleet and standards being used on that study. The second option is preferred, because on a workspace typically there are many vehicle fleets, road networks and standards; therefore, it is difficult to know which of these is being used on the study that you want to review.

Projects

Under Projects there are many projects designed to show the different features of HDM-4. To review a project, double click on the project name.

01a Paving Project Justification

This project performs the economic justification of upgrading a gravel road with 300 AADT to a surface treatment standard. Two alternatives are compared: (i) keep the road unsealed with a maintenance policy of routine maintenance, regravelling when gravel thickness reaches 50mm and grading every 182 days, and (ii) paved the road the first year of the evaluation period and then maintain the road with a maintenance policy of routine maintenance, patching and resealing when the damaged area reaches 20%.
To define a project, you have to follow the steps: (i) define project details, (ii) specify alternatives, (iii) analyze projects; (iv) multi-criteria analysis; and (v) generate reports. Each step is represented by a button at the right side of the screen. The first tab when you open a project and select “Define Project Details” contains the general description of the project where you define the project description, evaluation period, the start year, road network that contains the study road, vehicle fleet to be used, and the input and output currency. On all these case studies, the start year of the evaluation period is 2006.

Here you also define a very important evaluation option: (i) Analyze by Section or (ii) Analyze by Project. Analyze by section is selected if you want to evaluate one or many road sections and you want to treat each road section to be totally independent from the others, in effect, each road section is a separate project and HDM-4 will compute all the economic indicators (NPV and IRR) for all the alternatives defined for each section (project), allowing you to define the best section-alternative for each section. Analyze by project is selected if you want to evaluate many road sections as a dependent group or if you want to evaluate the construction of a bypass, where without the project you have one section and with the project you have two sections (the original road and the bypass). In this case, for each project-alternative you define one or many sections with corresponding maintenance or improvement standards, and HDM-4 computes the global economic indicators for each project-alternative, without presenting the economic indicators per section. Note that the screens under the Specify Standards button changes with your option.

In this case study because we are evaluating only on road section (or project), we select evaluation by section. The next tab shows the study sections where you define which of the road sections stored on the “North Region Project Roads” road network to include on the study. To show all available roads, select “Show unselected sections” box. To select a road section, select the “Include in analysis” and “Include in study” boxes, where
a red mark will appear. If you are reviewing a workspace, here you have the option to select a section and press the following boxes “View/Edit Section”, “View/Edit Network”, or “View/Edit Fleet” to be able to review or edit the contents of a road network or vehicle fleet defined previously.

At the Study Sections, you also define the traffic growth rate that should be assigned to each section to be included on the study. Select a road and press “Assign Growth Set” to view the available options that were previously defined at the vehicle fleet.

At the “Specify Alternatives” step, one defines the alternatives that will be evaluated for each road section or project. Here HDM-4 version 2.05 offers two totally different input interface options: (i) the new explorer style interface of HDM-4 version 2.0 and; (ii) the classic style interface of HDM-4 version 1.3. The classic interface is shown below and is used on all these case studies because the author considers the classic interface the best option for novice HDM-4 users.
When you install HDM-4 version 2.05, by default both options are installed and HDM-4 selects the new version 2.0 explorer style interface as shown below.

To switch to the classic interface you have to access the “HDM-4 Version 2.0 Options Tool” located under “Tools” under “HDM-4 Version 2.0” under “All Programs” at the Windows menu.
Here you can select the alternatives user interface, the interface language (English, French, etc.) and the input/output Window folders to be used by HDM-4. To follow these case studies, select the classic style and “View Details”.

At the classic interface, when the “View Details” is selected, you see the section(s) to be evaluated at the top and for the section that you highlight the corresponding defined alternatives at the bottom left. For each alternative that you highlight, you see the corresponding defined standards at the bottom right. If you unselect “View Details”, the information at the bottom of the screen is not shown (see below).
To view/edit the alternatives, press the “Edit Alternatives” button to get the following screen.

On this case study, one wants to evaluate two section-alternatives as illustrated on the graph below. On the without project alternative, one defines one maintenance standard that will keep the road unpaved during all the evaluation period. On the with project alternative, one defines an improvement standard that will pave the road the first year of the evaluation period to be followed on the second year of the evaluation period by a maintenance standard that will maintain the paved road in good condition over the evaluation period. Therefore, on HDM-4 each section-alternative is defined by one or more than one improvement or maintenance standard. One needs to define the standards that will be assigned to each alternative and when each standard becomes effective. We have the following:

<table>
<thead>
<tr>
<th>Alternative Name</th>
<th>Standard Type</th>
<th>Standard Name</th>
<th>Effective Years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base Alternative</td>
<td>Maintenance</td>
<td>Unpaved: Grading 182 Days + Regravelling</td>
<td>2006 to 2025</td>
</tr>
<tr>
<td>Paving in 2006</td>
<td>Improvement</td>
<td>Project 1 2006 Paving</td>
<td>2006</td>
</tr>
<tr>
<td></td>
<td>Maintenance</td>
<td>R+P+25mm Reseal at 20% Area</td>
<td>2007 to 2025</td>
</tr>
</tbody>
</table>
At the menu below, when you highlight a section-alternative name, HDM-4 shows the corresponding standards assignments at the right side. Note that all the standards shown under assignments correspond to the highlighted alternative.

![Image of menu]

At this menu, you have the following options.

- Add New Alternatives to add an alternative by giving a name to the new alternative.
- Edit Alternative to edit the name of a previously defined alternative. You can not change the name of the “Base Alternative”.
- Delete Alternative to delete a previously defined alternative. You can not delete the “Base Alternative”.
- Assign Maintenance to add a maintenance standard to an alternative. This option applies to highlighted alternative.
- Assign Improvement to add an improvement standard to an alternative. This option applies to.
- Edit Assignment to edit the maintenance or improvement assignments of the highlighted assignment.
- Remove Assignment to remove one highlighted maintenance or improvement assignment of the highlighted alternative.
- Copy Assignments to copy the maintenance and improvement assignments of the highlighted alternative to a clipboard.
- Paste Assignments to paste the maintenance and improvement assignments stored on the clipboard to the highlighted alternative.

If you highlight the maintenance standard (Unpaved: Grading 182 Days +Regravelling) of the Base Alternative and press Edit Assignment you get the following screen where you can select a standard and define the calendar year when the standard becomes effective. This screen is similar to the one you get when you select to Assign Maintenance or Assign Improvement.

![Image of Edit Assignment screen]
When you assign/edit a standard, you select a standard and enter the calendar when the standard becomes effective, which should be a year during the evaluation period defined on the General tab under Define Project Details. A standard is effective from the defined start year up to the end of the evaluation period or until another standard becomes effective. A very important rule of HDM-4 is that at a given calendar year only one maintenance standard is effective; therefore, it is an error to define two or more maintenance standards starting at the same calendar year. If maintenance and an improvement standard are defined to be effective on the same calendar year, the improvement standard will take precedence during the execution of the improvement work. The following examples illustrate these observations considering an evaluation period from 2006 to 2025.

<table>
<thead>
<tr>
<th>Standard</th>
<th>Effective From Year</th>
<th>Observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maintenance 1</td>
<td>2006</td>
<td>Maintenance 1 is effective from 2006 to 2025.</td>
</tr>
<tr>
<td>Maintenance 1</td>
<td>2006</td>
<td>Maintenance 1 effective from 2006 to 2011 and Maintenance 2 from 2012 to 2025.</td>
</tr>
<tr>
<td>Maintenance 2</td>
<td>2006</td>
<td>Maintenance 1 effective from 2006 to 2008, Improvement 1 effective from 2008 to 2025, and Maintenance 2 from 2009 to 2025. The improvement standard takes precedence over a maintenance standard when the improvement works are being scheduled on the same year.</td>
</tr>
<tr>
<td>Maintenance 1</td>
<td>2010</td>
<td>Error because no maintenance standard was defined for 2006 to 2009.</td>
</tr>
<tr>
<td>Maintenance 1</td>
<td>2006</td>
<td>Error because only one maintenance standard can be effective during a calendar year. In this case HDM-4 will select only one of the standards to be effective from 2006 to 2025. HDM4 will not combine the two standards.</td>
</tr>
</tbody>
</table>

Once you review the specification of alternative, you can press the Analyze Project button to review the following information. At the Setup Run tab, you define if you want to conduct economic analysis, enter the discount rate, decide to include accident costs, setup some evaluation flags, decide to perform asset valuation, and define the Windows folder where all the output data should be located (Run Data Export Directory). On these case studies,
the Run Data directory is setup to be C:\HDM-4 v2\Results; if you want to change the directory, press the Browse button and select a new Windows folder.

Under the Sensitivity tab, you can define optionally some sensitivity scenarios by defining multiplier factors on key sensitivity parameters. The example below shows the base scenario in which all multipliers are set to one; and three sensitivity cases considering increasing the net costs by 20%, decreasing the net benefits by 20%, and a combination of the two.

Under the Run Analysis tab, you press the Start button to start the evaluation.
The status area on the middle of the screen presents some evaluation warnings and the location of input data errors, if encountered. The last line indicates if the evaluation was completed without any errors and the total analysis time.

The Multi-Criteria Analysis button is used to define the inputs of a multi-criteria analysis, which is an optional analysis that does not affect the results of the economic evaluation. On this case study no multi-criteria analysis was defined.

To view the results of the evaluation, you press the Generate Reports button to get the screen below that shows that the HDM-4 output reports are grouped in categories.
When performing an economic evaluation of a project that improves the condition of a pavement, it is good practice to review first the roughness progression over time because user benefits are a direct function of roughness. Under the Deterioration/Work Effects folder, select the Average Roughness by Section (Graph) report, which shows that the roughness progression under the two alternatives is satisfactory. In year 1, the roughness is around 14 IRI, m/km that decreases substantially to 3 IRI, m/km with the paving improvement. Without the project, the roughness remains high with some reduction in roughness the years regravelling is applied (2012, 2018, and 2022). The roughness progression after paving considers routine maintenance, patching and a reseal when damaged area reaches 20% that is done in 20xx, although that can not be clearly observed on the chart. To close a report, press on the X at the top right corner of the report.
To review the resulting costs, open the Cost Streams and Economic Evaluation folder and select the Road Agency and User Costs (Undiscounted) report that shows for each sensitivity scenario and for each section-alternative the stream of undiscounted road agency costs, road user costs, exogenous costs, and total transport costs.

You can magnify the report by increasing the zoom and select which section-alternative and sensitivity scenario to view by selecting your choice at the left side area of the report. For example, below one can review the costs of the base alternative under the base sensitivity scenario with 100% zoom. The capital costs represent the regravelling costs and the recurrent costs the routine maintenance and grading. The road user costs, Motorized (MT) and Non-Motorized (NMT), are a function of the average roughness of the section at the given year, the terrain and the vehicle characteristics. The total transport costs are the sum of all the other costs. Note that the regravelling costs are the same in years 2011, 2017, and 2021 because on an economic evaluation one does not consider inflation, expressing all costs in constant current costs.
Below one can review the paving option. In this case, the capital costs includes the paving cost in 2006, a resealing in 2020 (when the damaged area reached 20%) and the residual value of the paving cost at the end of the evaluation period, 2025.

After computing these undiscounted cost streams, HDM-4 compares the two alternatives computing the resulting flow of net benefits of the project alternative compared with the base alternative. Open the report Comparison of Cost Streams (Undiscounted) to review the comparison, which shows at the last column the stream of total net benefits.
Evaluating the stream of total net benefits, HDM-4 computes the corresponding Net Present Value (NPV) and the Economic Internal Rate of Return (EIRR) of the project, which are given in two HDM-4 reports: (i) Economic Analysis Summary and (ii) Economic Indicators Summary. Open the report Economic Analysis Summary to view the economic evaluation results.

Here you find, for each sensitivity scenario, the undiscounted and discounted increase in road agency costs, savings in road user costs, and the resulting net economic benefits (NPV), along with the project EIRR. We are interested on the discounted NPV to assess if the project is economically justified. If the NPV, discounted at the given discount rate, is positive, the project is economically justified. In this case the project has a NPV of US$ 0.49 million and an EIRR of 16.0%, indicating that the project is economically justified.
Under a worst case scenario of agency costs increasing by 20% and user benefits decreasing by 20%, the project EIRR becomes 10.5%.

Open the report Economic Indicators Summary to view the economic evaluation results on a different format. Here you find, for each sensitivity scenario, the discounted increase in road agency costs, discounted decrease in road user costs, the discounted net economic benefits (NPV), the EIRR, discounted road agency and capital road agency costs, and the ration between the NPV and the road agency costs and road agency capital costs. The author prefers to view the results in this report because the economic evaluation indicators for all alternatives being evaluated appear in one single table.

01b Paving Project Justification with 50% Generated Traffic

This project performs the economic justification of the same paving project described above with the only difference that a new project-alternative was added that considers that generated traffic materializes after paving. Generated traffic is defined at the screen used to assign or edit an improvement standard for a given project-alternative. Open the project, go to specify standards, press the Edit Alternatives button, highlight the “Paving in 2006 with Generated Traffic” alternative, highlight the “Project 1 2006 Paving” improvement standard and press the Edit Assignment button to get the following screen.
At the bottom of the screen, notice that Generated Traffic was selected for this project-alternative. To view the characteristics of the generated traffic press the Generated Traffic button.

Here one defines the description of the generated traffic, relative year that is the number of year after the improvement standard trigger until generated traffic starts, and the amount of generated traffic over the years, which can be defined in a number of ways by highlighting a period (column) and editing it and/or by adding periods. The choices per period are given on the screen below. In this case study, we selected to define the generated traffic as a percent of the normal traffic in the current year (50% for all vehicles) over all the evaluation period.

Start the Run Analysis and once the evaluation is completed, view the report MT AADT (by vehicle), under the Traffic reports. Here you can check if the generated traffic is being modeled properly. For each vehicle, alternative and year, HDM-4 presents the normal traffic (first line), generated traffic (second line) and total traffic.
View the report Economic Indicators Summary, under Cost Streams and Project Evaluation. Here one can see that with generated traffic, the project EIRR increases to 19.8%

01c Paving Project Justification with Exogenous Benefits and Costs

This project performs the economic justification of the same paving project described above, without generated traffic, with the only difference that a new project-alternative was added that considers that exogenous benefits and costs materialize after paving. Exogenous benefits and costs are defined at the screen used to assign or edit an improvement standard for a given project-alternative, similar to the generated traffic.
One selects to include social exogenous benefits and costs and defines the stream of exogenous benefits and costs. In this case study, we defined exogenous social benefits in the amount of 100,000 per year over the evaluation period and an exogenous environmental mitigation cost of 50,000 during the first year after paving.

Run the analysis and view the report Road Agency and User Costs Streams, under Cost Streams and Project Evaluation to check if the net social/exogenous costs were modeled properly. In this case, with exogenous benefits and costs, the project EIRR is 21.4%
01d Paving Project Formulation

This project performs the economic justification of the same paving project described above, without generated traffic or exogenous benefits and costs, with the only difference that new project-alternatives were defined that evaluate postponing the paving of the road to 2007, 2008 and 2009. In this case we are not only interested on justifying paving the road, we want to use the HDM-4 model to find the best project-alternative from an economic evaluation consideration. The following screen shows the definition of paving the road in 2008, where an unpaved road maintenance standard is applied in 2006 and 2007, the paving is done in 2008 and a paved road maintenance standard is applied after 2009.

The chart below shows the resulting NPV compared to the present value of road agency costs, which shows that while all alternatives are economically justified (NPV greater than zero), the optimal alternative is to postpone the paving to 2007 (highest NPV). Note that this graph is not produced automatically by HDM-4, it was done in Excel from data collected from HDM-4 reports.
02a Paved Maintenance Policy Justification

This project performs the economic justification of a periodic maintenance policy on an asphalt concrete road with 1,500 AADT in fair condition (3.0 IRI, m/km). The maintenance standard named “R+P+Rec. AC Type I at 8.0 IRI” is assigned to the Base Alternative over the evaluation period. It includes: (i) recurrent maintenance road works applied every year (drainage works and miscellaneous works), (ii) 100% pothole patching applied when the number of potholes per km is greater than one, effectively patching all the potholes every year, and (iii) reconstruction of the pavement when the roughness reaches 8 IRI, m/km, but not before 2011.

There could be different reconstruction options in the country (for example, different layer thickness, width and costs); therefore, a reconstruction “Type I” was defined, which represents an asphalt concrete reconstruction in this case. An additional criterion was added, as shown below, to avoid having this reconstruction being executed before 2011, which was considered too close to the first year of the evaluation period (a minimum 6 years of project benefits is recommended). The Base Alternative should represent realistic road works that the road agency will perform over the evaluation period in case the project is not implemented. A common mistake on running HDM-4 is to define the Base Alternative as a do-nothing case, which is not realistic over the evaluation period.
The project-alternative is name “Overlay 40mm at 4.0 IRI”. The maintenance standard assigned to the project-alternative (“R+P+40mm Overlay at 4.0 IRI”) includes the same drainage, miscellaneous and patching works of the Base Alternative and a condition responsive 40mm overlay applied when the roughness reaches 4 IRI, m/km. Note that under the names convention of these case studies, “R” indicates recurrent works and “P” patching.

In this case, the thickness of the overlay (40mm) and the roughness threshold (4.0 IRI) were selected based on engineering judgment, and the objective of the case study is to economically justify these choices. One can check the road deterioration results by looking at the report “Average Roughness by Section (Graph)” that is shown below.

The reconstruction of the Base Alternative is done in 2016 and for the project-alternative a first 40mm overlay is done in 2010 and a second one in 2021. The overlays reduce the roughness of the road to around 2.5 IRI, m/km and the reconstruction to around 2.0 IRI, m/km. To view a summary of the road deterioration for the two alternatives, one can view the report “Pavement Condition Summary”. To view a detailed report on the road deterioration of bituminous roads, one can view the report “Pavement
Condition (Bituminous Pavements)” as shown below. This report presents year by year, for all project alternatives, the traffic and all the road condition parameters estimated by HDM-4 at the end of the year before road works and after road works.

The economic evaluation results show that the EIRR of this maintenance policy is 40.2% that indicates that periodic maintenance has a high economic justification for this level of traffic.

02b Paved Maintenance Policy Optimization

This project finds the optimal maintenance policy for an asphalt concrete road with 1,500 AADT in fair condition (3.0 IRI, m/km). This is the same road evaluated on the previous case study; the only difference is that now we are evaluating many possible maintenance policies to determine the policy with highest NPV. All the project-alternatives being evaluated consider recurrent maintenance (drainage works and miscellaneous works) and 100% patching over the evaluation period, and the following alternative capital works:

<table>
<thead>
<tr>
<th>Alternative Name</th>
<th>Capital Road Work</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base Alternative</td>
<td>Reconstruction at 8 IRI, m/km</td>
</tr>
<tr>
<td>25mm at 10%</td>
<td>25 mm reseal at 10% damaged area</td>
</tr>
<tr>
<td>25mm at 20%</td>
<td>25 mm reseal at 20% damaged area</td>
</tr>
<tr>
<td>25mm at 30%</td>
<td>25 mm reseal at 30% damaged area</td>
</tr>
<tr>
<td>40 mm at 3.0 IRI</td>
<td>40 mm overlay at 3.0 IRI, m/km</td>
</tr>
<tr>
<td>40 mm at 4.0 IRI</td>
<td>40 mm overlay at 4.0 IRI, m/km</td>
</tr>
<tr>
<td>40 mm at 5.0 IRI</td>
<td>40 mm overlay at 35.0 IRI, m/km</td>
</tr>
<tr>
<td>80 mm at 3.0 IRI</td>
<td>80 mm overlay at 3.0 IRI, m/km</td>
</tr>
<tr>
<td>80 mm at 4.0 IRI</td>
<td>80 mm overlay at 4.0 IRI, m/km</td>
</tr>
</tbody>
</table>
Each maintenance standard is given a name that should indicate the road work items that will be executed under the standard. For example, a standard named “R+P+40mm Overlay at 4.0 IRI” will execute recurrent maintenance (R) plus patching (P) every year plus a 40mm overlay when the road roughness reaches 4.0 IRI. By defining the project-alternatives in this manner, we are able to determine the road work (25mm reseal, 40mm overlay or 80mm overlay) and the corresponding intervention threshold that maximizes the NPV. As shown below, the optimal alternative is to perform a 40mm overlay at 4.0 IRI, m/km, because it has the highest NPV, despite the fact that to perform the 40mm overlay at 5.0 IRI has the highest EIRR. One never uses the EIRR to compare project-alternatives.

<table>
<thead>
<tr>
<th>Alternative Name</th>
<th>NPV (M$)</th>
<th>EIRR (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base Alternative</td>
<td>0.00</td>
<td>NA</td>
</tr>
<tr>
<td>25mm at 10%</td>
<td>0.41</td>
<td>28.0</td>
</tr>
<tr>
<td>25mm at 20%</td>
<td>0.41</td>
<td>31.6</td>
</tr>
<tr>
<td>25mm at 30%</td>
<td>0.39</td>
<td>35.9</td>
</tr>
<tr>
<td>40mm at 3.0IRI</td>
<td>0.48</td>
<td>20.4</td>
</tr>
<tr>
<td>40mm at 4.0IRI</td>
<td>0.65</td>
<td>40.2</td>
</tr>
<tr>
<td>40mm at 5.0IRI</td>
<td>0.60</td>
<td>63.2</td>
</tr>
<tr>
<td>80mm at 3.0IRI</td>
<td>0.07</td>
<td>12.9</td>
</tr>
<tr>
<td>80mm at 4.0IRI</td>
<td>0.38</td>
<td>24.5</td>
</tr>
<tr>
<td>80mm at 5.0IRI</td>
<td>0.55</td>
<td>38.0</td>
</tr>
</tbody>
</table>

This is an example of evaluating condition responsive maintenance standards that is appropriate to evaluate roads in good to fair condition, where we want to determine the optimal maintenance policy and corresponding level of service (average roughness over the evaluation period) and annualized maintenance costs over the evaluation period. The disadvantage of this method is that a priori we don’t know when the capital road works will be applied. To find out when the capital road works will be applied, one needs to search for the information on the road deterioration or the flow of road agency costs reports.

**02c Paved Road Works Programming**

This project finds the optimal work program for an asphalt concrete road with 1,500 AADT in fair condition (3.0 IRI, m/km). This is the same road evaluated on the previous case study; the only difference is that now the project-alternatives are defined on a different manner to facilitate the definition of the work program for the given road. In this case, one defines the possible capital road works (for periodic maintenance or rehabilitation) that could be executed in the road and then one defines different maintenance standards, scheduling these different types of road work in different calendar years.
The maintenance standards are set up to schedule these road works in 2006, 2007, 2008, or 2009, taking into account that the evaluation period will begin in 2006. The maintenance standard named “R+P+40mm Overlay in 2006”, for instance, has been assigned the following work items:

- Miscellaneous
- Drainage
- Patching
- 2006 40mm Overlay
- Next 40mm Overlay, when the road roughness reaches 4.0 IRI

The item “Miscellaneous” represents the component of routine maintenance that does not affect the deterioration of the carriageway (for example, maintenance of vertical and horizontal signs). In this case, the miscellaneous activities are scheduled every year. The item “Drainage” represents the component of routine maintenance that impacts the deterioration of the carriageway by affecting the drainage of the road (for example, cleaning culverts or mowing grass). In this case, the drainage activities are also scheduled every year. The item “Patching” represents the amount of pothole patching being done on the roads. In this case, all potholes will be patched every year. The item “2006 40m Overlay” represents the first capital road work that will be executed on the road, in this case, scheduled for 2006, as shown below.

The item “Next 40mm Overlay” represents the future periodic maintenance road work (in this case an overlay) that will be done on the road, after the initial road work is executed. In this case, the next overlay is condition-
responsive and is triggered when the road roughness reaches 4.0 IRI, as shown below. An additional criterion was added to avoid having this second overlay being executed before 2012, which is considered too close to the first overlay.

In this case study, the following possible project alternatives were defined:

- Base Alternative (reconstruction at 8.0 IRI, m/km)

The economic evaluation results show that among these project-alternatives, the best project-alternative is to execute a 40 mm overlay in 2011 with an NPV of 0.662 M$, as shown below.
03a Widening Evaluation

This project evaluates improving the standard of a 7.0 meter wide bituminous road in fair condition (4.0 IRI, m/km), carrying traffic of 10,000 AADT with 39% trucks and buses, and a roadside friction of 0.6 that represents a reduction on vehicle speeds due to disturbances along the road (pedestrians, garage entrances, shops stands, etc.). The project-alternatives being evaluated are the following.

- Base alternative (reconstruction at 6.0 IRI, m/km)
- Pavement reconstruction in 2006
- Partial widening to 10.0 meter carriageway
- Widening to 4 lanes.

The base alternative reconstructs the pavement when the roughness reaches 6.0 IRI, m/km, but no sooner than 2009. The roughness threshold for the reconstruction of the base alternative is lower in this case study, compared to the previous case, studies due to the high traffic of the road. The reconstruction keeps the carriageway width at 7.0 meters with a cost of 300,000 US$ per km. The second project-alternative executes the pavement reconstruction in 2006, the first year of the evaluation period. The third project-alternative resurfaces the road in 2006 with an 100 mm overlay and at the same time widens the carriageway from 7.0 to 10.0 meters with an overall cost of 600,000 US$ per km. The fourth project-alternative resurfaces the current carriageway in 2006 with 100 mm overlay and at the same time constructs a new 7.0 meter carriageway, widening the road to 4 lanes with an overall cost of 1,000,000 US$ per km.

On HDM-4, a reconstruction can be defined either as a maintenance standard or as an improvement standard. In this case, for the base alternative, it was defined as a maintenance standard similar to the previous case studies, but for the second project-alternative, it was defined as an improvement standard, as shown below, under the name Project 3 2006 Reconstruction.

When you define an improvement standard, on the General tab, you define the Improvement Type (pavement reconstruction, partial widening, lane addition, realignment, upgrading, etc.) and the inputs of the other tabs change according to your selection.
For the reconstruction improvement standard, the main inputs are the following:

- Improvement Type = Pavement Reconstruction
- Duration = 1 year
- Increase in width = 0 meters
- Intervention = 2006
- Financial cost = 300,000 per km
- Structural number = 5.0

For the partial widening standard, the main inputs are the following:

- Improvement Type = Partial Widening
- Duration = 1 year
- Speed Flow Type = Wide Two Lane Road
- Accident Class = Wide Two Lane Road
- Increase in width = 3 meters
- Intervention = 2006
- Financial cost = 600,000 per km
- Resurfacing of existing carriageway = 100 mm overlay
- Structural number = 5.0
- Roadside friction = 0.6

For the widening to 4 lanes standard, the main inputs are the following:

- Improvement Type = Lane Addition
- Duration = 1 year
- Speed Flow Type = Four Lane Road
- Accident Class = Four Lane Road
- Increase in width = 7 meters
- Intervention = 2006
- Financial cost = 1,000,000 per km
- Resurfacing of existing carriageway = 100 mm overlay
- Structural number = 5.0
- Roadside friction = 1.0
In this case, the benefits of the reconstruction are originating exclusively from the reduction of the road roughness because the speed flow type (capacity) and the roadside friction (reduction in speeds) of the road don’t improve with the reconstruction. With partial widening, the roughness of the road improves and the capacity of the road changes to Wide Two Lane; thus, benefits are originating also from reduced travel times due to some relieve on congestion. With widening to 4 lanes, the capacity of the road more than doubles, changing to Four Lane Road speed flow type, and the roadside friction increases to 1.0, indicating that it was eliminated; thus, yielding more travel time benefits.

When evaluating a project that deals with congestion benefits, it is good practice to review the report Volume/Capacity Ratio by Flow Period located under the Traffic reports. The report presents the Volume/Capacity ratio for all period of the year, for all alternatives over the evaluation period. One can observe that under the widening to 4 lanes alternative, the Volume/Capacity ratio during the most congested hours of the year (Period 1) reduces from 0.55 to 0.20; while on the partial widening alternative reduces only to 0.49.

One can review the predicted operating speeds by opening the report MT Vehicle Operating Speeds located under the Road User Effects reports. The report presents the operating speeds for all periods of the year, all vehicle types, and alternatives over the evaluation period. One can observe that under the widening to 4 lanes alternative, the speed of a delivery vehicle on Period 1 increases from 58.6 to 107.3 km/hour while on the partial widening alternative increases only to 72.9 km/hour.
The economic evaluation results show that among these project-alternatives, the best project-alternative is to widen the road to 4 lanes with an NPV of 8.99 M$ and an EIRR of 25.5%, as shown below.

03b Widening Evaluation w Accidents

This project evaluates improving the standard of the road defined on the previous case study, but this time including accident benefits. By widening the road, one expects a reduction in accidents, particularly when widening the road to 4 lanes with a median. The accident rates of two lanes, wide two lanes, and four lanes in this case study region were defined on the accident classes configuration and are summarized below. These accident rates, in number per 100 million vehicle-km, are only sample figures and don’t represent HDM-4 default values; therefore, you should obtain proper accident rates for your country.
To include accident benefits in the evaluation, you select Include Accident Cost at the Setup Run tab under Analyze Projects, as shown below. In this case, the cost of an accident with fatalities is 200,000 $ per accident, the cost of an accident with injuries is 20,000 $ per accident, and the cost of an accident with damage only is 2,000 $ per accident.

The economic evaluation results show that among these project-alternatives, the best project-alternative is to widen the road to 4 lanes with an NPV of 13.68 M$ and an EIRR of 32.3%.
04a Bituminous or Concrete Comparison

This project evaluates the comparison of upgrading an unpaved road with 1,000 AADT, surfacing it with a surface treatment, asphalt concrete or rigid concrete pavement. Each surface type option is characterized on different improvement standards with the following main characteristics and with improvement type defined as upgrading.

Surface Treatment Pavement

- Cost = 200,000 US$ per km
- Structural Number = 1.5
- Thickness = 25 mm

Asphalt Concrete Pavement

- Cost = 300,000 US$ per km
- Structural Number = 2.5
- Thickness = 50 mm

Rigid Concrete Pavement

- Cost = 700,000 US$ per km
- Surface Type = JPCP with dowels
- Thickness = 190 mm

After the road is upgraded, each surface type is maintained over the evaluation period with a corresponding maintenance standard. The surface treatment road receives a 25mm reseal when the damaged area reaches 30%, the asphalt concrete road receives a 40mm overlay at 4.0 IRI, m/km, and the rigid pavement is maintained with slab replacement and joint sealing.

The economic evaluation results show that among these project-alternatives, the best project-alternative is to upgrade to surface treatment with an NPV of 7.12 M$ and an EIRR of 65.2%.
05a Road User Effects

This project is designed to compute unit road user costs, in US$ per vehicle-km, and emissions for a road in good condition (2 IRI, m/km) and without congestion. The evaluation has the following characteristics:

- Evaluation period = 1 year
- Road length = 1.0 km
- Road roughness = 2 IRI, m/km
- Road traffic = 10 AADT, one vehicle per vehicle type
- Traffic growth rate = 0%

The unit road user costs results can be found on the report “MT RUC Summary per veh-km by Vehicle” under the Road User Effects reports, as shown below. This report shows on the first row the annual average vehicle operating costs per vehicle-km, on the second row the annual average travel time costs per vehicle-km, and on the third row the annual average road user costs per vehicle-km. You can view the road user costs components, the free-flow speed and the operating speed at the other available reports.

The emissions quantities results, in grams per 1000 vehicle-km, can be found on the report “Emissions by Vehicle Type” under the Environmental Effects reports, as shown below. This report shows, for seven types of emissions and for all vehicle types, the unit emission quantities.
Programmes

Under Programmes, one road works program is presented to show the features of this evaluation option.

North Region Road Sections Evaluation

In this case, we are evaluating the periodic maintenance and rehabilitation road works program for 16 homogenous road sections with different traffic and condition characteristics. The structure of the inputs for this case study is very similar to the case study 02c Paved Road Works Programming, with the only difference that we are evaluating 16 road sections at once, as shown below.
For each road section, two to three possible road works (40mm overlay, 80mm overlay, 25mm reseal, etc.) were selected based on the road section traffic and condition and these road works were scheduled occurring in 2006, 2007, 2008 or 2009. Thus, HDM-4 will identify the optimal road work and timing per road section for a given budget scenario.

When evaluating many road sections, it is a good idea to exclude the annual vehicle data and the vehicle period data from the HDM-4 output file, to increase the speed of the evaluation and reduce the size of the output file. These intermediate results will still be computed by HDM-4, but they will not be placed on the output file. You exclude these data by selecting your choice at the Run Setup, as shown below.

After the evaluation is completed, you can view the resulting unconstrained road works program at the tab “Unconstrained Programme” under the Generate Programme option, as shown below. This table shows the road works that should be executed per road section to maximize the total NPV of the road sections. The table shows the year of the road works, the financial
capital cost of the road work during that year (M$), the recurrent cost (M$), the cumulative capital costs (M$), and the ratio NPV per present value of capital costs. We can observe that in 2006, 9.91 M$ are needed in total for capital costs and from 2006 to 2009, 14.74 M$ are needed in total for capital costs (see capital cumulative cost column), which is equivalent to roughly 3.5 M$ per year. We can also note that the disbursements from 2006 to 2007 are not equally distributed, but are concentrated in 2006 and in 2009. This represents the theoretical optimal unconstrained scenario, but does not represent a practical scenario.

In order to obtain a practical unconstrained road works program and to assess possible budget constraints, we can use the Perform Budget Optimization option of HDM-4, as shown below.
In this case, the 3.5 M per year budget scenario is defined as maximum expenditures of US$ 3.5 million per year during the first four years of the evaluation period and US$ 10,000 million in years 5 to 20, representing an unconstrained budget scenario in years 5 to 20.

The optimization is done once the Perform Budget Optimization button is pressed and the results can be seen on Optimized Programme tab, as shown below for the 3.5 M per year scenario.

**Strategies**

Under Strategies, two examples of a network strategic evaluation are presented. For information regarding, the North Region Evaluation case study refer to the following publication.

Applying the HDM-4 Model to Strategic Planning of Road Works
By Rodrigo Archondo-Callao

The South Region Evaluation case study has a similar structure, but evaluates a smaller network matrix of road classes.