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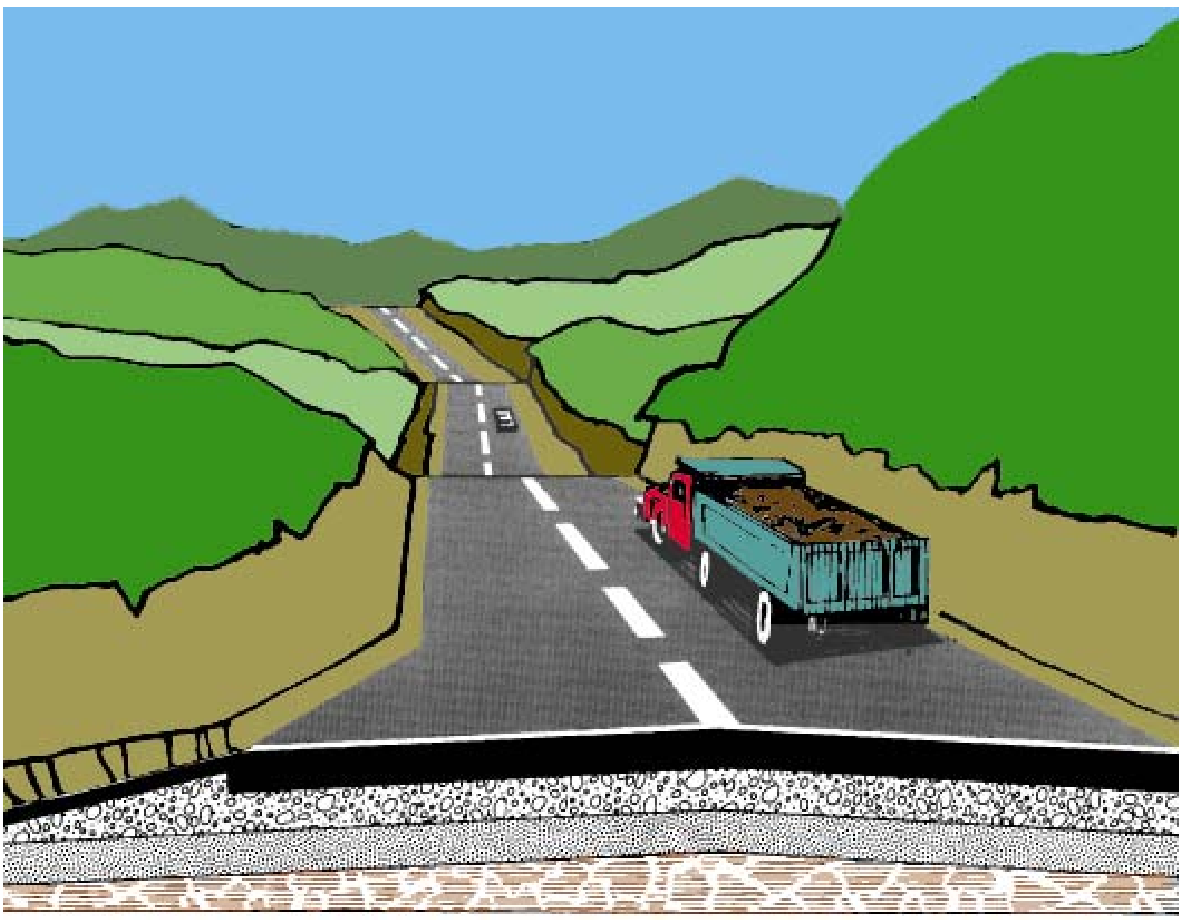
Applying the HDM-4 Model to Strategic Planning of Road Works

Rodrigo Archondo-Callao



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APPLYING THE HDM-4 MODEL TO STRATEGIC PLANNING OF ROAD WORKS

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ABBREVIATIONS AND DATA NOTES

AADT	Annual Average Daily Traffic
ERR	Economic Rate of Return
HDM-III	Highway Design and Maintenance Standards Model
HDM-4	Highway Development and Management Model
IRI	International Roughness Index
NPV	Net Present Value
ROCKS	Road Costs Knowledge Systems

All dollar amounts are U.S. dollars unless otherwise indicated.
Billion means 1,000 million.

1 INTRODUCTION

The Highway Development and Management Model (HDM-4)[1] is a software system for evaluating options for investing in road transport infrastructure. Worldwide, the HDM-4 model is most commonly used as a basis for *feasibility studies*, in which a road project is evaluated in terms of its economic viability. A more comprehensive type of evaluation based on HDM-4 is a *network evaluation*, which assesses an entire road network to help decision makers in their strategic planning of road investments and/or the definition of a rational road works program, with or without budget constraints. A network economic evaluation is the most challenging use of the model, but the effort is well justified given the potential savings to be achieved on transport costs by comparing various project alternatives and performing an optimization under budget constraints.

This technical note presents the author's experience applying HDM-4 and its predecessor, the Highway Design and Maintenance Standards Model (HDM-III)[2], to road network strategic planning evaluations in developing countries, with the objective of providing recommendations and tools to the readers who are involved in strategic planning activities. The purpose of the evaluations, the methodology itself, the input requirements, the challenges, and the presentation of results to decision makers are each reviewed in turn.

The methodology described here attempts to take advantage of all the capabilities of HDM-4, giving due attention to its limitations, and produce usable results. The examples provided represent actual HDM-4 inputs and results obtained from many HDM-4 studies in developing countries in recent years; they were selected from different studies to best illustrate a given evaluation step, but do not otherwise represent a pattern or relationship.

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[1] Highway Development and Management Model (HDM-4)
http:// hdmglobal.com

[2] World Bank Road Software Tools
http://worldbank.org/roadsoftwaretools/

2 HDM-4 MODEL EVALUATIONS

The objective of a project *feasibility study* is to assess its economic viability, ensuring that the project yields positive net economic benefits as expressed by the Net Present Value (NPV), at a given discount rate. In a project *economic evaluation*, two project alternatives are evaluated: a "without project scenario" and a "with project scenario". Annual road agency and road user costs are computed for both alternatives over a defined evaluation period, and total costs to society are compared for the two scenarios. The resulting stream of net benefits to society is used to compute the economic indicators that help determine the project's economic viability. It is desirable that more than two project alternatives be evaluated per project, which permits the economic comparison of the project alternatives and the recommendation that the project alternative that maximizes the project's net benefits (NPV) be implemented.

A network-level evaluation is typically used in cases where strategic planning of all roads is managed by a road agency or in cases of programming of road works on candidate roads in fair and poor condition. A network evaluation involves synthesizing the available network data, evaluating many roads or road classes, evaluating different project alternatives per road, performing a budget constraints optimization, and summarizing and presenting the results in a useful way.

Although HDM-4 includes a life-cycle analysis of the recurrent maintenance requirements of different project alternatives, the model is not generally used for planning and programming of recurrent *maintenance road works*, such as crack sealing, patching, or routine maintenance. The model is used for planning and programming of *capital activities*, such as reseal, overlay, reconstruction, widening, and new construction.

HDM-4 evaluates the performance of paved and unpaved roads; therefore, the model could be used to evaluate a network comprised both of paved and unpaved roads. However, most strategic planning evaluations reviewed by the author involved only the country's network of *paved* roads. Some reasons for this approach are that (i) typically there is little information on the condition and traffic load of unpaved roads; (ii) in some countries, most unpaved roads are *not* managed by the main road agency; and (iii) combining paved and unpaved roads in one single evaluation is methodologically challenging due to the different nature of these roads. If one does perform a combined evaluation, the "without project alternative" for the paved and unpaved roads need to be carefully defined so as to avoid being biased in the benefits calculations.

3 STRATEGIC PLANNING ROLE IN A ROAD AGENCY

Strategic planning consists of evaluating an entire road network with aggregate data to provide a macro view of the network and to help decision makers:

- Define the rational allocation of resources among networks, regions, different types of road work and so forth;
- Calculate approximate quantities, costs, and benefits;
- Estimate performance outcomes;
- Gain insight into the impact of budget constraints; and
- Program their road works in a rational way.

A strategic planning study shows how budget constraints affect the road agency's expenditures, the costs to road users, the benefits to society, and the road network's condition. The results of a strategic planning evaluation typically include:

- An overview of the network's current traffic load and condition;
- The routine maintenance, periodic maintenance, and rehabilitation needs under a "without budget constraints scenario" and several "under budget constraints scenarios";
- A comparison of the network net benefits for different levels of road agency expenditures (reflected in different budget scenarios);
- The expected road condition and road user costs for different budget scenarios; and
- For each budget scenario, the solution catalog for each road class that maximizes the network's net benefits to society.

Getting an overview of the network's current traffic load and condition does not require the use of HDM-4. A series of network monitoring indicators are computed and current network statistics are presented in graphical form. Table 3-1 presents an example of network monitoring indicators.

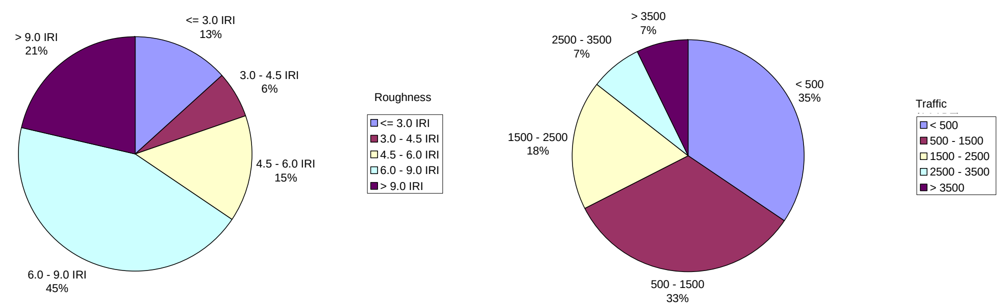
Table 3-1. Example of monitoring indicators		
Network Length		
Road network length	Km	20,822
Road network length that is unpaved	Km	18,474
Road network length that is paved	Km	2,348
Road network length that is paved	%	11.3%
Network Density		
Road network per thousand land area	Km/1000 sq km	172.08
Road network per thousand total population	Km/1000 persons	4.16
Road network per thousand rural population	Km/1000 persons	10.41
Road network per thousand vehicles	Km/1000 vehicles	138.81
Road network per $ million GDP	Km/million $	4.53
Network Condition		
Percentage of road network in good and fair condition	%	27.7%
Percentage of paved road network in good and fair condition	%	66.1%
Percentage of paved road network with roughness 4 IRI, m/km,[3] or less	%	50.1%
Paved roads average roughness weighted by km	IRI, m/km	5.29
Paved roads average roughness weighted by vehicle-km	IRI, m/km	4.35
Percentage of unpaved roads that are all-weather roads	%	4.5%
Network Standards		
Percentage of unpaved roads with 30 AADT[4] or less	%	63.5%
Percentage of unpaved roads with 300 AADT or more	%	1.5%
Percentage of paved roads with 300 AADT or less	%	4.0%
Percentage of paved roads with 10,000 AADT or more	%	5.0%
Network Utilization		
Annual motorized vehicle utilization	Million vehicle-km	2,481
Annual freight carried over road network	Million ton-km	6,027
Annual passengers carried over road network	Million pass-km	13,447
Average network annual average daily traffic	Vehicles/day	326
Network Asset		
Current road asset value	Million $	929.0
Current road asset value as a share of maximum road asset value	%	80.1%
Current road asset value as a share of GPD	%	20.2%

Figure 3-1 shows an example of a network's current condition and traffic statistics (distribution of network length by roughness and traffic ranges), derived from actual network data.

[3] International Roughness Index (IRI), measures the "bumpiness" of a road—the total anticipated vertical movement a vehicle would experience over a given stretch of road, usually expressed in meters/kilometer; the lower the value, the smoother the ride.

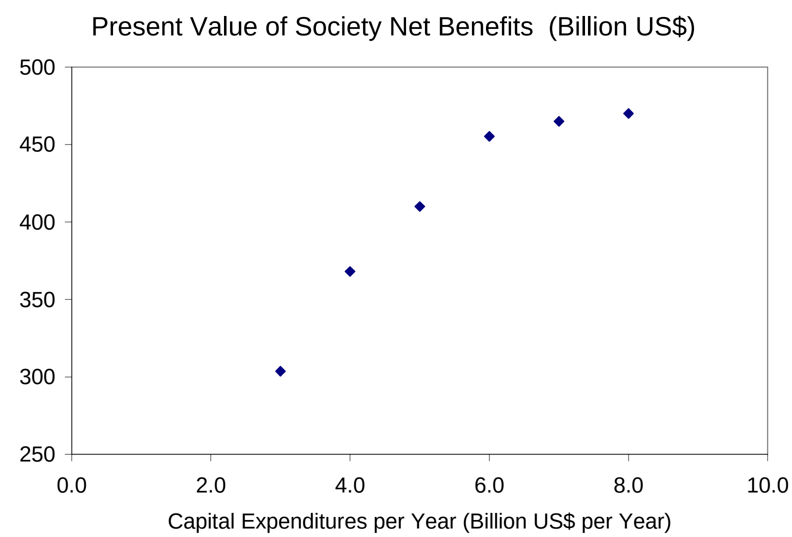
[4] Annual Average Daily Traffic (AADT), the total volume of vehicle traffic in both directions of a highway or road for a year divided by 365 days; it is a useful and simple measurement of how busy a road is.

Figure 3-1. Current network condition and traffic statistics example



The network costs, benefits, and performance are evaluated with HDM-4 under different budget scenarios. Figure 3-2 presents an example of a typical efficiency frontier graph that shows the impact of budget constraints on net benefits to society, where each point represents a budget scenario. It shows that: (i) the recommended road agency capital expenditures are US$8.0 billion per year, with a corresponding present value of net benefits to society of US$470 billion; and (ii) the net benefits to society decrease only marginally if road agency capital expenditures are reduced to US$6.0 billion, but the net benefits to society decrease considerably for expenditures below US$6.0 billion.

Figure 3-2. Example of impact of capital expenditures on benefits to society



It is desirable to compare the budget scenarios in terms of benefits and costs to society. Table 3-2 presents an example based on the comparison of four different budget-constraint scenarios, involving expenditures in years 1 through 5 equivalent to 75 percent, 50 percent, 25 percent and 5 percent of the “practical unconstrained budget scenario” (100 percent) respectively. The latter is defined as the budget scenario that evenly spreads the expenditures during the next five years and that maximizes the NPV of the network. The table shows: (i) the network’s Net Present Value of benefits to society (NPV); (ii) the present value of costs to the road agency, road users and society as a whole; (iii) the present value of the losses to society resulting from budget constraints; and (iv) the benefit-cost ratio.

For example, under the unconstrained budget scenario, it is estimated that each dollar of incremental *costs* brings 5.1 dollars of incremental *benefits*.

Table 3-2. Economic comparison of different budget scenarios

	Scenario 100% 61 M US$/year	Scenario 75% 50 M US$/year	Scenario 50% 34 M US$/year	Scenario 25% 17 M US$/year	Scenario 5% 3 M US$/year
	Net Present Value of Economic Society Benefits, NPV (M US$)				
NPV	292	284	245	190	55
Agency	289	269	265	250	226
Road Users	4,755	4,783	4,826	4,895	5,055
Total Society	5,044	5,052	5,091	5,145	5,281
	Present Value of Total Society Costs Losses Compared with 100% Scenario (M US$)				
Losses	0	8	47	101	237
	Present Value of Costs and Benefits Compared with Do-nothing Scenario (M US$)				
Cost	70	50	46	31	7
Benefit	362	334	290	221	62
Benefit Cost Ratio	5.1	6.7	6.4	7.2	8.6

Budget constraint in years 1 to 5. No budget constraint in years 6 to 20.

Figure 3-3 illustrates the impact budget constraints can have on the *total* expenditures of a road agency. The Figure shows total expenditures (in millions of dollars) required, during the periods 2006-2010 and 2011-2025, for different budget constraints in the period 2006-2010. Under the "without budget-constraints scenario" (US$61 million/year from 2006-2010), US$305 million are needed from 2006-2010 and US$174 million are needed from 2011-2025, while US$85 million are needed from 2006-2010 and US$584 million are needed from 2011-2025 if expenditures only amount to US$17 million/year from 2006-2010. The figures in the latter case represent a 40 percent increase in the road agency's total expenditures over the 20-year evaluation period compared to the former case. The evaluation shows that by spending *more* now, the road agency will spend *less* in the future.

Figure 3-3. Example of impact of budget constraints on total road agency expenditures

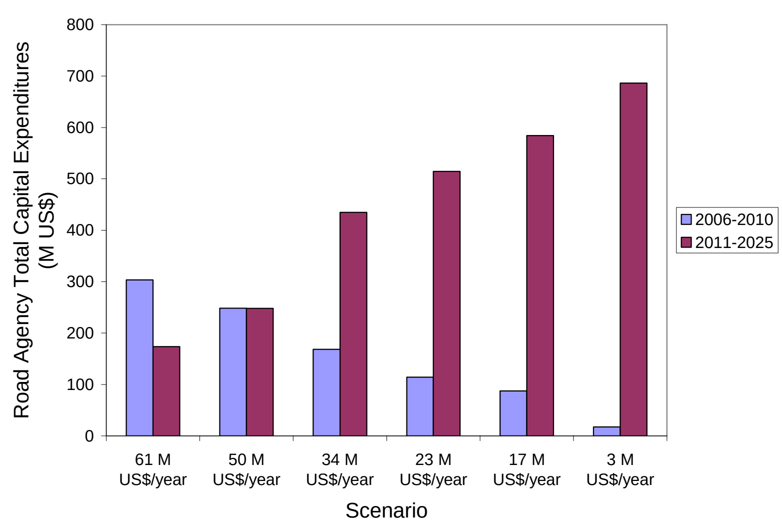


Figure 3-4 illustrates the impact of budget constraints on a road agency's *annual* expenditures. The Figure shows road agency expenditures required, in US$ per km-year, during the 2006-2010 and 2011-2025 periods for different budget constraints in the period 2006-2010. The higher the budget constraints (the lower the annual expenditures) from 2006-2010, the higher the annual expenditures required from 2011 to 2025. Expenditures in the order of US$34 million/year more or less stabilize next year's (2006-2010) and future (2011-2025) annual expenditures.

Figure 3-4. Example of impact of budget constraints on annual road agency expenditures

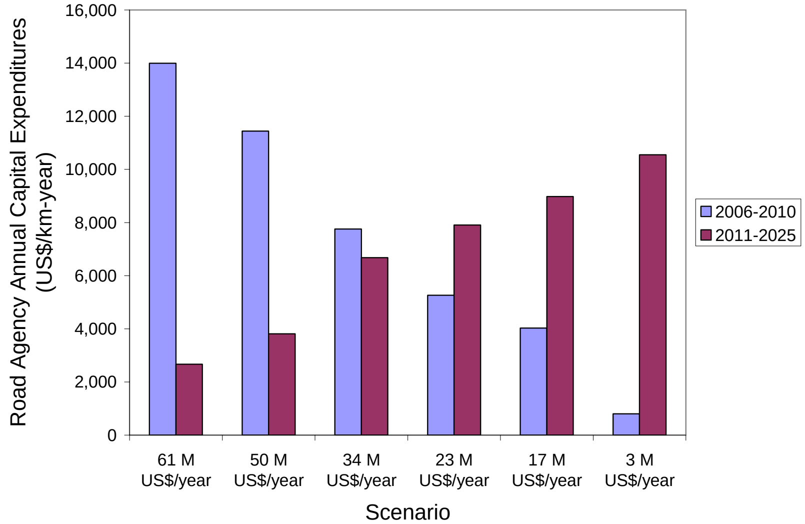


Figure 3-5 presents an example of the percentage of the network in stable condition under different budget scenarios in year 2010 and the current percentage in 2006. A network in "stable" condition contains roads in good to fair condition that require routine or periodic maintenance only. Each country defines the specific characteristics of these roads. In the example given, stable roads were defined simply as roads with a roughness profile characterized by an IRI value under 4.5 m/km. In other countries, surface distress indicators or deflections or traffic load could complement this definition.

Figure 3-5. Example of a stable network

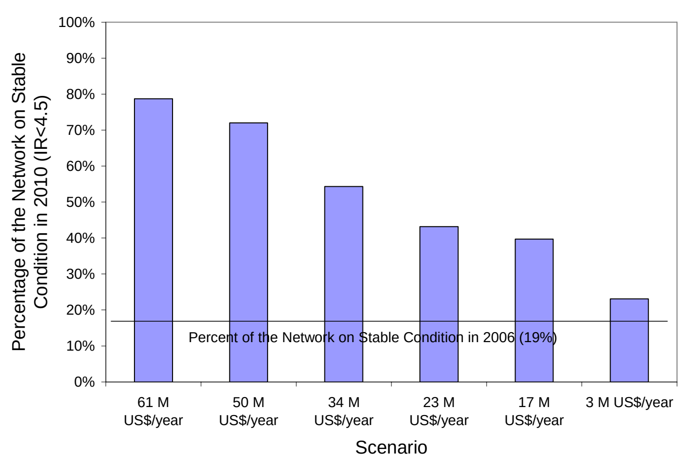


Table 3-3 presents an example of a road condition forecast presenting the network utilization (vehicle-km) and network length (km) in each road condition category (good, fair, or poor) per year for the "without project budget scenario" and the "unconstrained budget scenario". The table shows that under the unconstrained budget scenario: (i) the proportion of the network length in good condition (IRI, m/km<3.5) increases from 51 percent in year zero to around 75 percent in year four; and (ii) the proportion of the network utilization (vehicle-km) in good condition increases from 60 percent in year zero to around 83 percent in year four. Under the "without project budget scenario", the condition of the network in year four will be much worse—with the network length in poor condition figure increasing from 2 percent to 18 percent and network utilization increasing from 1 percent to 13 percent. The network *utilization* per road condition category was found to be a better indicator than network *length* per road condition category because it takes into account the number of road users traveling on a given road condition category.

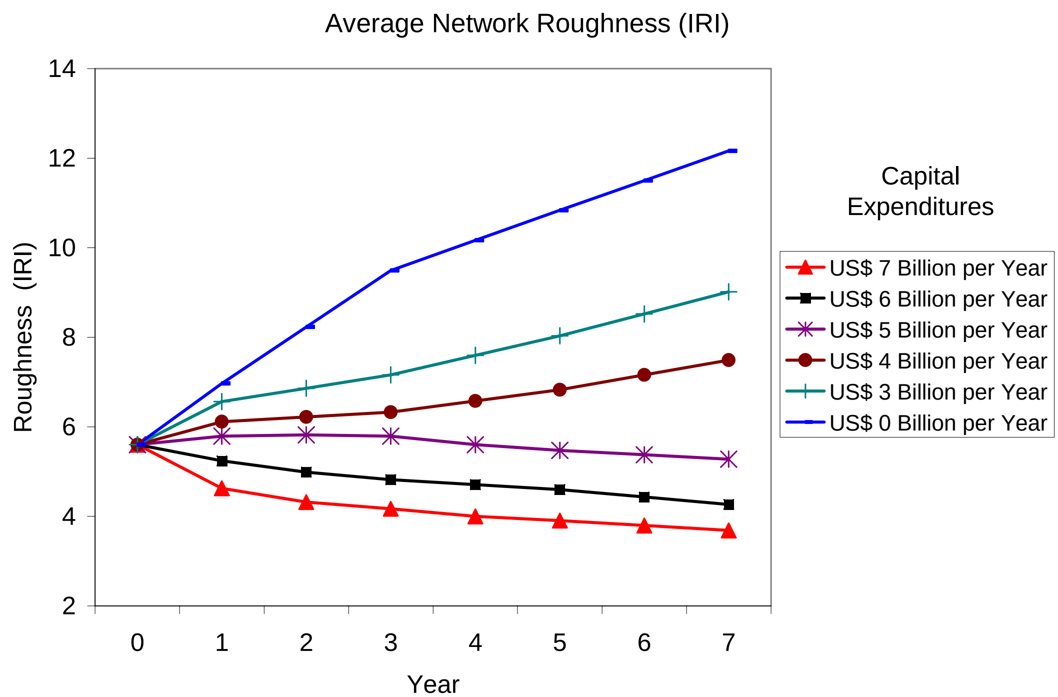
Table 3-3. Example of impact of budget versus no-budget scenarios on network utilization and condition

	Year 0	Year 1	Year 2	Year 3	Year 4
Network Utilization (Vehicle-km) - Without Project Budget Scenario					
Good (IRI, m/km < 3.5)	60%	61%	61%	61%	60%
Fair (3.5 < IRI, m/km < 5.5)	40%	37%	35%	34%	27%
Poor (IRI, m/km > 5.5)	1%	2%	4%	5%	13%
Network Utilization (Vehicle-km) - Unconstrained Budget Scenario					
Good (IRI, m/km < 3.5)	60%	63%	70%	76%	83%
Fair (3.5 < IRI, m/km < 5.5)	40%	37%	29%	23%	17%
Poor (IRI, m/km > 5.5)	1%	0%	2%	1%	1%
Network Condition (km) - Without Project Budget Scenario					
Good (IRI, m/km < 3.5)	51%	52%	52%	52%	52%
Fair (3.5 < IRI, m/km < 5.5)	47%	44%	39%	38%	31%
Poor (IRI, m/km > 5.5)	2%	4%	9%	10%	18%
Network Condition (km) - Unconstrained Budget Scenario					
Good (IRI, m/km < 3.5)	51%	54%	61%	68%	75%
Fair (3.5 < IRI, m/km < 5.5)	47%	44%	34%	28%	22%
Poor (IRI, m/km > 5.5)	2%	2%	5%	4%	3%

One of the most useful graphs for budget planning purposes is one that presents the development of a network's average roughness (as measured by its IRI-value) in the evaluation period, weighted by network length or network utilization, under different budget scenarios.

Figure 3-6 presents the example of a network whose roughness is weighted by *network utilization* (vehicle-km). It shows that: (i) around US$4.5 billion per year is needed to maintain the network in the same road condition it is in today; (ii) the optimal level of capital expenditures is US$7 billion per year, a level which will improve the network's roughness to around 3.1 IRI in year six; and (iii) without any capital expenditures on the network, the network roughness will increase to around 11.0 IRI in year six.

Figure 3-6. Example of impact of capital expenditures on a network's average roughness



The impact (of intervention or non-intervention) on the network's condition over time can be measured by the change in its IRI value (which quantifies a network's degree of roughness) or any other road condition indicator.

Figure 3-7 presents the network's average surface distress area, with and without a project, along with the percentage of the network in good, fair and poor condition—defined as a function of the *surface distress area.*

Figure 3-7. Example of impact of a project on network condition

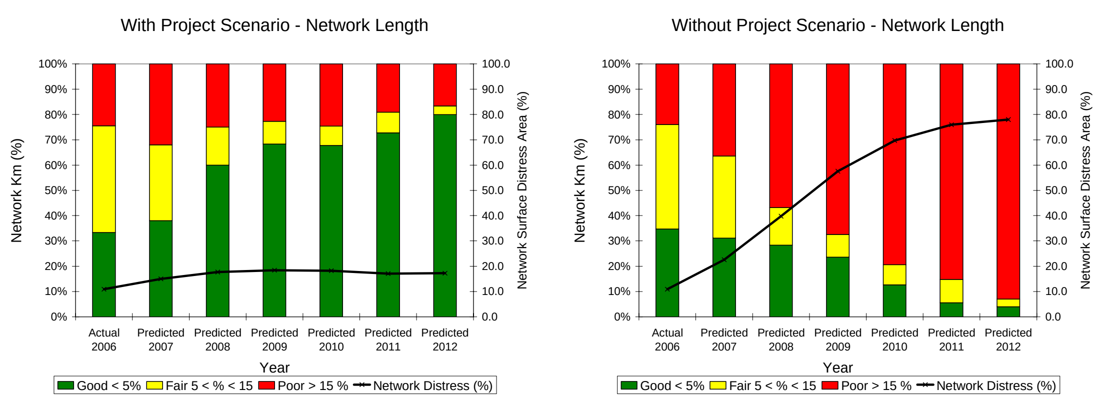
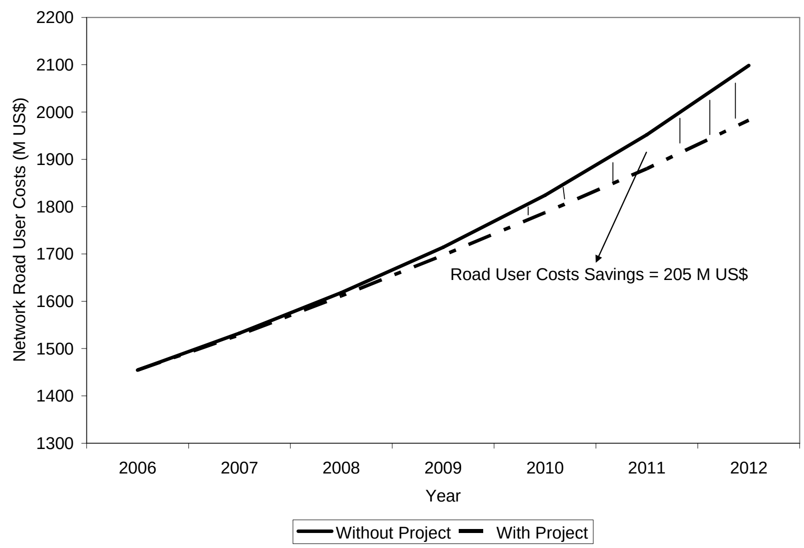


Figure 3-8 presents an example of the impact on the network's total road user costs, with and without a project. In this example, road users save US$250 million over the next six years if a road rehabilitation and maintenance project is implemented.

Figure 3-8. Example of impact of capital works on road users



Once a given budget scenario is selected, one can summarize the resulting work program. Table 3-4 presents an example of allocation of expenditures per network type and per year for a given budget scenario (US$34 million per year on average), which shows that 61 percent of the road agency's expenditures should be dedicated to works on *international* roads.

Table 3-4. Example of road works allocation of resources

Recommended Road Works Allocation for 50% Budget Scenario (M US$)							
Network	2006	2007	2008	2009	2010	Total	Percent
International	34.75	24.88	0.33	12.07	30.19	102.22	61%
National	0.23	10.10	20.47	19.77	0.93	51.50	31%
Local			11.75	2.82		14.57	
Grand Total	34.98	34.98	32.54	34.67	31.12	168.28	100%

Table 3-5 shows an example of a road works program that specifies expenditures (in million US$) and total length (in km) of the affected roads per type of road work and per year, for a given budget scenario, which shows that: (i) the average expenditures are around US$315 million per year; (ii) almost half of the expenditures are needed for 50 mm overlays; and (iii) the total length of the roads affected will diminish in year 4, which will consist exclusively of 50 mm overlays. In this example, the expenditures are more or less evenly distributed over time; one could evaluate a different budget scenario, in which the expenditures increased over time, taking into account the ability of local contractors to ramp up to meet the construction requirements.

Table 3-5. Example of a road works program

Expenditures (Million US$)					
Road Work Activity	Year 1	Year 2	Year 3	Year 4	Total
Slurry Seal	133.4	45.5	132.2		311.1
Overlay 25 mm		146.5	98.1		244.6
Overlay 50 mm	191.0	106.3	85.7	306.4	689.5
Overlay 80 mm	7.8	2.6			10.4
Total	332.2	300.9	316.0	306.4	1,255.6
Road Works (km)					
Road Work Activity	Year 1	Year 2	Year 3	Year 4	Total
Slurry Seal	6,804	2,322	6,746		15,872
Overlay 25 mm		3,077	2,061		5,138
Overlay 50 mm	2,354	1,310	1,056	3,774	8,494
Overlay 80 mm	64	21			85
Total	9,222	6,729	9,863	3,774	29,588

Table 3-6 presents a typical solution catalog optimized for a specific budget scenario, which is a useful planning tool. For each road class, the catalog presents a *recommended type of road work* and its *optimal timing* (identified by a "solution code"). In Table 3-6, the recommended road work is identified by a code on the *left* of the solution code (O1, O2, etc.) and the optimal calendar year by a code on the *right* of the solution code (Y1, Y2, etc.). Separate tables can present the corresponding road agency expenditures and economic indicators (NPV, ERR, etc.) per road class.

Table 3-6. Example of a solution catalog

Total Bituminous Network (2-lane equivalent length, km)						
Traffic Range	Road Condition Range (Roughness, IRI, m/km)					
(Vehicles/day)	< 3	3 to 4	4 to 5	5 to 6	6 to 8	>= 8
1 to 200	Base	Base	Base	Base		
201 to 500	Base	Base	O3 Y5	O3 Y5	O5 Y5	O5 Y4
501 to 1000	O1 Y6	O2 Y5	O3 Y2	O3 Y4	O5 Y3	
1001 to 2000	O1 Y6	O1 Y3	O3 Y3	O3 Y3	O4 Y2	
2001 to 4000	O1 Y3	O3 Y4	O3 Y1	O3 Y1	O4 Y1	O4 Y1
4001 to 6000	O1 Y2	O2 Y2	O3 Y1	O3 Y1	O4 Y1	
6001 to 10000	O2 Y6	O3 Y4	O3 Y1			O4 Y1
> 1000-	O3 Y5	O3 Y2	O4 Y1	O4 Y1		

Base: Base alternative	Y1: Work in 2004
O1: Slurry Seal	Y2: Work in 2005
O2: Reseal 25 mm	Y3: Work in 2006
O3: Overlay 50 mm	Y4: Work in 2007
O4: Overlay 80 mm	Y5: Work in 2008
O5: Reconstruction	Y6: Work in 2009

Another option is to present a similar table per road condition and traffic load, this time presenting the appropriate road work per road class, from an economic point of view, assuming that the road works are done in year 1. A second table can present the appropriate road work per road class if the recommended road works are postponed by one year, a third table postponing the road works by two years, and so on.

4 STRATEGIC PLANNING EVALUATION STEPS

Strategic planning of road works with HDM-4 involves the following steps:

- Collect all available road network data per homogeneous road section and enter it into a road network database if needed;
- If road network data is not available per homogeneous road section, collect network aggregate data instead;
- Analyze the road network database or the road network aggregate data to establish a representative matrix of road classes;
- Define representative matrix cells' length and other attributes;
- Identify possible country-specific types of road work and estimate unit costs of the identified types of road work in *financial costs* and *economic costs* (net of taxes and subsidies);
- Define proper pragmatic project alternatives to be evaluated per matrix cell, considering the condition and traffic load of the roads and current practices in the country;
- Establish country-specific road user costs;
- Define the planning period, evaluation period and discount rate;
- Enter input data into HDM-4 and run HDM-4;
- Evaluate different budget scenarios with HDM-4;
- Obtain from the HDM-4 output files, the raw results;
- Import the HDM-4 results into Excel and prepare output tables, charts and reports;
- If a road network database is available, optionally, bring the results of the strategic planning study into the road network database, for example, to produce maps of the results per road section.

Figure 4-1 presents a flowchart of the above steps, which are presented in more detail in the following sections. Annex 1 presents a case study of a strategy evaluation based on HDM-4 version 2.04.

4.1 Establishing a representative road matrix

Network data is collected on an aggregate level, without obtaining detailed information per road section, and the evaluation is typically based on an analysis of representative road classes. Aggregate attributes are typically collected for network length, surface type, traffic load, and road condition, and assembled to characterize a series of typical road classes representing the network. If the network's total length is relatively small (less than 3,000-4,000 km) and there is a network database with detailed information per homogeneous road section (traffic load, condition, surface type, etc.), then the network can be evaluated on the basis of each homogeneous road section, without the need to define a matrix of road classes. Evaluating homogeneous road sections yields more precise results, but can become a cumbersome process if there are too many different road sections (>300), particularly in the definition of project alternatives per road section, and it is not always feasible due to the lack of a complete network database. The disadvantage of evaluating a matrix is the fact that the results are not as precise because one characterizes each road class with averages of averages of the road attributes.

Figure 4-1. Strategic planning of road works flowchart

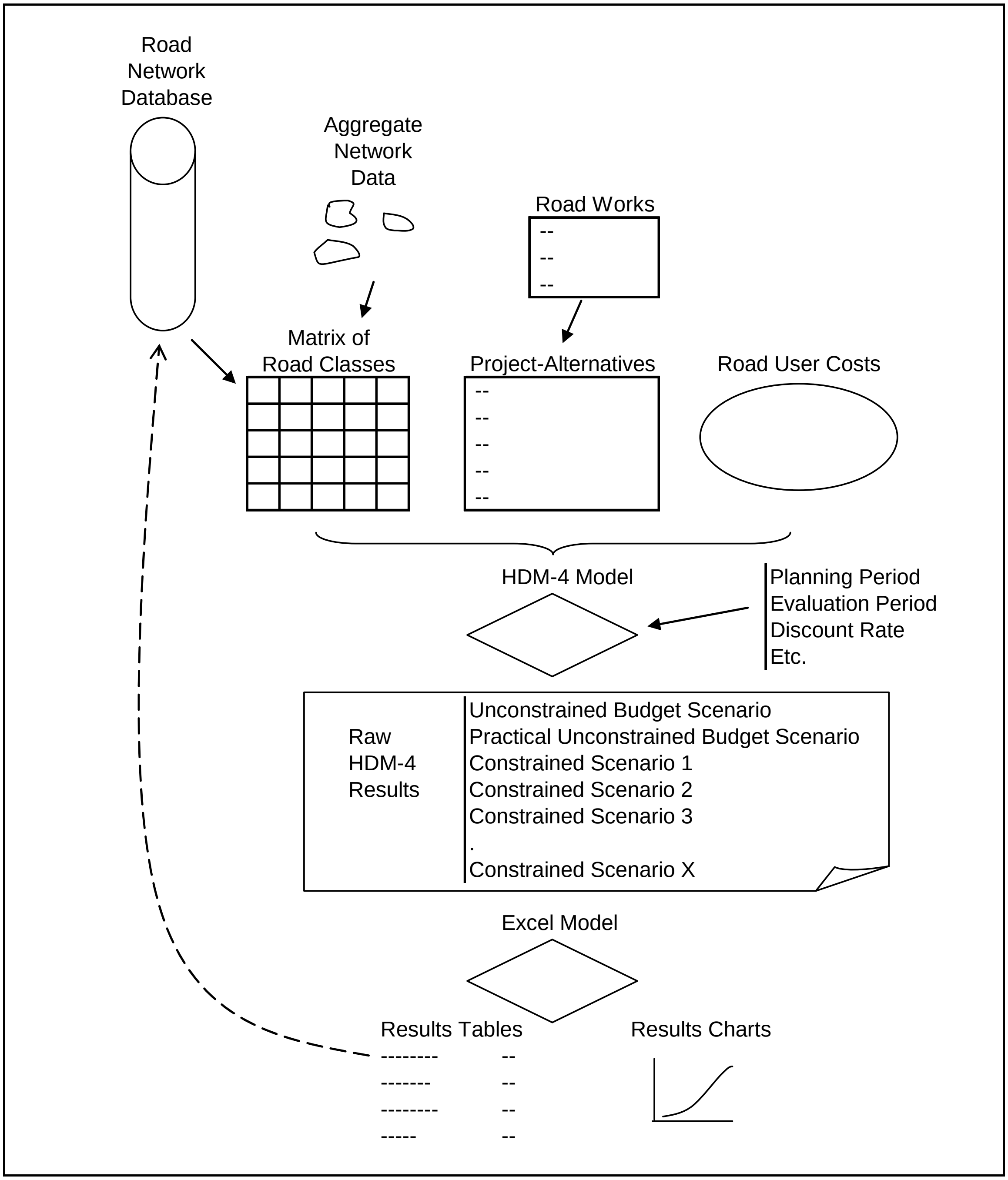


Table 4-1 presents an example of road classes, which shows that: (i) the entire bituminous network was evaluated and converted to a two-lane equivalent network length, (ii) eight traffic levels were identified to reflect motorized daily traffic load, (iii) six road condition classes were defined exclusively as a function of roughness, and (iv) of the 48 possible road classes, 41 road classes (the ones with a length unequal to zero km.) were characterized and evaluated with HDM-4.

Table 4-1. Example of road classes for strategic planning evaluation

Total Bituminous Network (2-lane equivalent length, km)								
Traffic Range	Road Condition Range (Roughness, IRI, m/km)							
(Vehicles/day)	< 3	3 to 4	4 to 5	5 to 6	6 to 8	>= 8	Total	Percent
1 to 200	161	93	143	77			474	1%
201 to 500	290	792	362	163	11	21	1,638	4%
501 to 1000	1,659	2,371	993	92	77		5,191	12%
1001 to 2000	4,040	4,472	952	252	14		9,731	22%
2001 to 4000	5,445	4,060	1,005	21	2	8	10,541	24%
4001 to 6000	3,808	2,050	117	12	9		5,996	14%
6001 to 10000	4,449	1,587	134	10		3	6,183	14%
> 10000	2,552	1,293	88	9	2		3,945	9%
Total	22,404	16,717	3,794	636	114	31	43,697	100%
Percent	51%	38%	9%	1%	0%	0%	100%	

Table 4-1 is an example of a very simple network matrix where only *traffic load* and *road condition* are considered. The size and structure of the network matrix varies from case to case and is a function of the country, the network characteristics and available network data. To illustrate this point, Table 4-2 presents the road classes adopted for bituminous roads in different countries and shows that: (i) surface type, traffic load and condition are common to most evaluations; (ii) sometimes, to define the road condition, roughness is complemented by cracking or deflections or a surface distress index; (iii) geographic region, number of lanes, road width, functional classification or percentage of trucks may also be considered to better characterize the network; and (iv) the total number of possible road classes varies. Surface type, roughness and traffic load are typically included as criteria to define road classes because road user costs and user comfort are both functions of surface type and roughness, and road user benefits and road deterioration are functions of traffic load. If the matrix definition does not consider the number of lanes or the road width, the network length is expressed in two-lane equivalent length, converting four-lane roads into equivalent two-lane roads.

Table 4-2. Examples of road class categories

Country	Road Class Categories	No of Road Classes
Thailand	Traffic, Roughness	48
Pakistan	Surface Type, Traffic, Roughness, Cracking	120
Bangladesh	Functional Class, Number of Lanes, Traffic, Roughness	630
Brazil (DNIT)	Surface Type, Traffic, Roughness, Deflection	128
Brazil (Goias)	Surface Type, Traffic, Roughness, Cracking	168
Brazil (Bahia)	Surface Type, Traffic, Roughness	50
Kyrgyz	Surface Type, Traffic, Roughness, Number of Lanes, Functional Class	750
Morocco	Surface Type, Climate, Traffic, Roughness, Cracking, Width	648
Mexico (SCT)	Surface Type, Traffic, Roughness, Cracking, Width	360
Mexico (Guanajuato)	Surface Type, Traffic, Roughness, Deflection	100
Vietnam	Surface Type, Number of Lanes, Traffic, Condition Class	252
Kosovo	Traffic, Roughness, Cracking, Deflection	72
Chile*	Surface Type, Traffic, Road Condition Class, Geographic Region	72
Honduras*	Surface Type, Traffic, Roughness, Cracking	120
Lebanon*	Surface Type, Traffic, Roughness, Road Width	112
Nepal*	Traffic, Roughness, Surface Distress Index	80
Uruguay*	Surface Type, Traffic, Trucks Percent, Roughness, Surface Distress	129

* HDM-III evaluation

The total number of road classes doesn't necessarily coincide with the road classes evaluated with HDM-4 because a road class containing zero kilometers of the network is not included in the evaluation. In the studies presented in Table 4-2, on average, 45 percent of the road classes had zero kilometers. It is recommended that many road classes be defined, but to try to limit the evaluation to less than 400 road classes, thus enabling the use of HDM-4 more precise EBM-32 optimization algorithm, which cannot evaluate more than 400 road classes or road sections at one time. If more that 400 road classes are defined in HDM-4, the model will still perform the optimization, but with a less precise algorithm.

For a better optimization, one should have many *road classes* and, if possible, with broadly the same order of magnitude of number of kilometers. When defining the traffic level thresholds, one can adjust them in order to distribute the number of kilometers more or less evenly among traffic levels but, when defining the *road condition categories*, one should not attempt to distribute the kilometers evenly among these, as they should be defined purely on *technical* considerations. While several road classes should be defined, one should avoid having road classes with a very small number of kilometers (less than 5 or 10 kilometers) because they represent a very small percentage of the network. In this case, it is better to combine them into another cell.

The definition of the road condition categories varies by country, as these are a function of the network's specific characteristics, current practices and available network data. Table 4-3 presents some examples of road condition categories. Example 1 considers only roughness in five categories. Example 2 considers roughness and deflections in eight categories and is tailored for a network with roads characterized by low roughness and deflections. Example 3 considers roughness and cracking in 12 categories. In this case, it is important to include a category with zero cracking because that will indicate to HDM-4 that the cracking progression has not yet started. Example 4 considers an overall, subjective, condition index that varies from 1 (very good) to 5 (very poor). In this case, one can have, for example, the following definition: (i) very good requires only routine maintenance; (ii) good requires routine maintenance and preventive maintenance; (iii) fair requires routine maintenance and periodic maintenance; (iv) poor requires routine maintenance and partial reconstruction; and (v) very poor requires reconstruction. Example 5 considers a combination of roughness or cracking, which is not advisable because by combining the indicators one loses the individual characteristics of the road condition. The definition of the roughness, cracking and deflection ranges varies by country and there is no international standard for them.

It is possible to assign a label (for example, good, fair, poor) to each condition category (see example 1 in Table 4-3), but this should be done with care because typically this is associated with only one road condition indicator (for example, roughness, cracking or deflection), which represents only one dimension of the overall condition of the road. While one road may have low roughness and therefore could be labeled in “good” condition, it could also have high surface distress or deflections requiring rehabilitation works. If the road condition categories are defined with more than one road condition indicator (examples 2 and 3 above), it is recommended not to assign a label (good, fair, poor, etc.) to each condition category and to just identify them by letter (A, B, C, etc.).

Table 4-3. Examples of road condition categories

Example 1	Very Good		IRI < 2.5 m/km Roughness
	Good		2.5 m/km < IRI < 3.5 m/km Roughness
	Fair		3.5 m/km < IRI < 6.0 m/km Roughness
	Poor		6.0 m/km < IRI < 10.0 m/km Roughness
	Very Poor		IRI >= 10.0 m/km Roughness
Example 2	< 2.5 IRI, m/km Roughness	and	< 0.4 mm Benkelman Beam Deflection
	< 2.5 IRI, m/km Roughness	and	>= 0.4 mm Deflection
	2.5 - 3.0 IRI, m/km Roughness	and	< 0.4 mm Deflection
	2.5 - 3.0 IRI, m/km Roughness	and	>= 0.4 mm Deflection
	3.0 - 4.0 IRI, m/km Roughness	and	< 0.4 mm Deflection
	3.0 - 4.0 IRI, m/km Roughness	and	>= 0.4 mm Deflection
	>= 4.0 IRI, m/km Roughness	and	< 0.4 mm Deflection
	>= 4.0 IRI, m/km Roughness	and	>= 0.4 mm Deflection
Example 3	< 3.5 IRI, m/km Roughness	and	0 % Cracks
	< 3.5 IRI, m/km Roughness	and	1 - 20 % Cracks
	< 3.5 IRI, m/km Roughness	and	>= 20 % Cracks
	3.5 - 5.0 IRI, m/km Roughness	and	0 % Cracks
	3.5 - 5.0 IRI, m/km Roughness	and	1 - 20 % Cracks
	3.5 - 5.0 IRI, m/km Roughness	and	>= 20 % Cracks
	5.0 - 7.0 IRI, m/km Roughness	and	0 % Cracks
	5.0 - 7.0 IRI, m/km Roughness	and	1 - 20 % Cracks
	5.0 - 7.0 IRI, m/km Roughness	and	>= 20 % Cracks
	>= 7.0 IRI, m/km Roughness	and	0 % Cracks
	>= 7.0 IRI, m/km Roughness	and	1 - 20 % Cracks
	>= 7.0 IRI, m/km Roughness	and	>= 20 % Cracks
Example 4	1-Very Good		Subjective evaluation
	2-Good		Subjective evaluation
	3-Fair		Subjective evaluation
	4-Poor		Subjective evaluation
	5-Very Poor		Subjective evaluation
Example 5	< 2.5 IRI, m/km Roughness	and	< 5 % Cracks
	2.5 - 4.0 IRI, m/km Roughness	or	5 - 30 %Cracks
	>= 4.0 IRI, m/km Roughness	or	>= 30 % Cracks

Later, during the presentation of the results of the evaluation, one can define which road classes should be considered in good, fair, poor condition, etc. It is possible to define different road condition ranges for different paved surface types, for example, Asphalt Concrete or Surface Treatment Roads, but it is better to use the same ranges for all surface types, provided the road condition categories are not associated with a road condition label (good, fair, poor, etc.), such as in examples 2 and 3 above. By doing so, one can compare the distribution of the network by road condition categories among surface types.

4.2 Defining road class attributes

The number of kilometers in each road class can be obtained from: (i) querying a road network database or a pavement management system, which yields the precise number of kilometers that are needed for a refined evaluation; or (ii) from engineering estimates of the distribution of the network length by surface type, traffic load, condition, etc., which yields estimates that are sufficient for an approximate evaluation for broad planning purposes.

Once the number of kilometers is defined, the next step is to characterize each road class by defining the HDM-4 road attributes that represent the average characteristics of the road sections that belong to a road class. The HDM-4 road attributes can be roughly estimated based on engineering judgment, characterizing HDM-4 inputs based mostly on aggregate data, or can be obtained from statistically analyzing the data available in the road network database or pavement management system. If aggregate data is used, the data is converted to HDM-4 inputs using corresponding default values. Table 4-4 presents the HDM-4 road attributes, highlighting in bold the main road attributes.

In most cases, simple HDM-4 inputs based on aggregate data are used because, typically, detailed data covering the entire network is not available. An effort should be made to quantify the *key* HDM-4 attributes of a road class, i.e., the length, width, pavement type, climate zone type, geometry type, traffic load and traffic composition, roughness, deflection or structural number, cracking, raveling, potholes, rut depth, pavement age and construction quality. Engineering judgment and HDM-4 defaults can be used to define the other HDM-4 inputs.

Table 4-4. HDM-4 road attributes

Simple Aggregate HDM-4 Inputs	HDM-4 Inputs
Length (km) **Carriageway width (m)** **Motorized traffic (AADT)** **Traffic composition per vehicle type (%)** **Last surfacing year (calendar year)** **Pavement type** **Climate zone type** **Speed flow type** **Traffic flow pattern type**	Length (km) Carriageway width (m) Motorized traffic (AADT) Traffic composition per vehicle type (%) Last surfacing year (calendar year) Pavement type Climate zone type Speed flow type Traffic flow pattern type
Geometry type	Rise + Fall (m/km) Horizontal Curvature (deg/km)
Structural adequacy type	**Benkelman beam (mm) or FWD deflection (mm) or structural number (#)** Most recent surfacing thickness (mm) Previous/old surfacing thickness (mm)
Ride quality type	**Roughness (IRI, m/km)**
Surface condition type	**All structural cracking area (%)** **Ravelled area (%)** **Number of potholes (No./km)** **Mean rut depth (mm)** All transverse thermal cracking area (%) Wide structural cracking area (%) Edge break area (m2/km)
Surface texture type	Texture depth (mm) Skid resistance (SCRIM 50km/hour)
Road Works History	**Last rehabilitation (calendar year)** Last construction (calendar year) Last preventive treatment (calendar year)
Drain type	Drain type
Drain condition type	Drain condition type
Construction quality type	Construction quality type

Key HDM-4 road attributes in bold

4.3 Defining road class identification codes

Each road class needs an identification code composed of up to six characters. For a simple matrix that is a function of surface type, traffic load and road condition, typically the following scheme of identification codes is used:

First character assigned to the surface type, for example:

A for Asphalt Concrete Roads
S for Surface Treatment Roads

Second character – a number – assigned to the traffic level, for example:

1	for 0 to 10 AADT
2	for 10 to 30 AADT
3	for 30 to 100 AADT
4	for 100 to 300 AADT
5	for 300 to 1,000 AADT
6	for 1,000 to 3,000 AADT
7	for 3,000 to 10,000 AADT
8	for 10,000 to 30,000 AADT

Third character – a letter – assigned to the road condition category, for example:

A	for < 2.5 IRI, m/km Roughness and < 0.4 mm Deflection
B	for < 2.5 IRI, m/km Roughness and >= 0.4 mm Deflection
C	for 2.5 - 3.0 IRI, m/km Roughness and < 0.4 mm Deflection
D	for 2.5 - 3.0 IRI, m/km Roughness and >= 0.4 mm Deflection
E	for 3.0 - 4.0 IRI, m/km Roughness and < 0.4 mm Deflection
F	for 3.0 - 4.0 IRI, m/km Roughness and >= 0.4 mm Deflection
G	for >= 4.0 IRI, m/km Roughness and < 0.4 mm Deflection
H	for >= 4.0 IRI, m/km Roughness and >= 0.4 mm Deflection

Following this system, road class A6B represents an asphalt concrete road with 1,000 to 3,000 AADT with < 2.5 IRI, m/km roughness and >= 0.4 mm reflection. Another option could be to assign the third and fourth character to the road condition, using the third character for the roughness and the fourth character for the deflection. In this case, for example, the road condition characters could be the following:

RX	for < 2.5 IRI, m/km Roughness and < 0.4 mm Deflection
RY	for < 2.5 IRI, m/km Roughness and >= 0.4 mm Deflection
SX	for 2.5 - 3.0 IRI, m/km Roughness and < 0.4 mm Deflection
SY	for 2.5 - 3.0 IRI, m/km Roughness and >= 0.4 mm Deflection
TX	for 3.0 - 4.0 IRI, m/km Roughness and < 0.4 mm Deflection
TY	for 3.0 - 4.0 IRI, m/km Roughness and >= 0.4 mm Deflection
UX	for >= 4.0 IRI, m/km Roughness and < 0.4 mm Deflection
UY	for >= 4.0 IRI, m/km Roughness and >= 0.4 mm Deflection

4.4 Defining road works

For an *economic* evaluation, the total cost of road works has to be estimated in *financial* and *economic* terms (net of taxes and subsidies) for all possible capital and recurrent road works that could be executed on the network. The country's design standards should support the road works to be performed; for example, there is no point in testing 40 mm overlay if the minimum overlay in the country is 50mm, unless one wants to use the evaluation to explore possible new design standards.

The number of capital types of road work evaluated is country-specific. While the minimum number of types of road work evaluated for bituminous networks is generally three (surface treatment resurfacing, asphalt concrete overlay and reconstruction), the maximum can reach more than 30 if different kinds of work, thicknesses, and other options are considered as well (with or without improving shoulders).

Table 4-5, an example of capital road work costs defined in a Latin American country, shows that: (i) different levels of periodic maintenance (P1 to P5) and rehabilitation (R1 to R2) were considered, and (ii) different predominant work activities were defined per type of road work. It is recommended that a 2-character code be assigned to each type of road work, which differentiates between *periodic* maintenance and *rehabilitation* works.

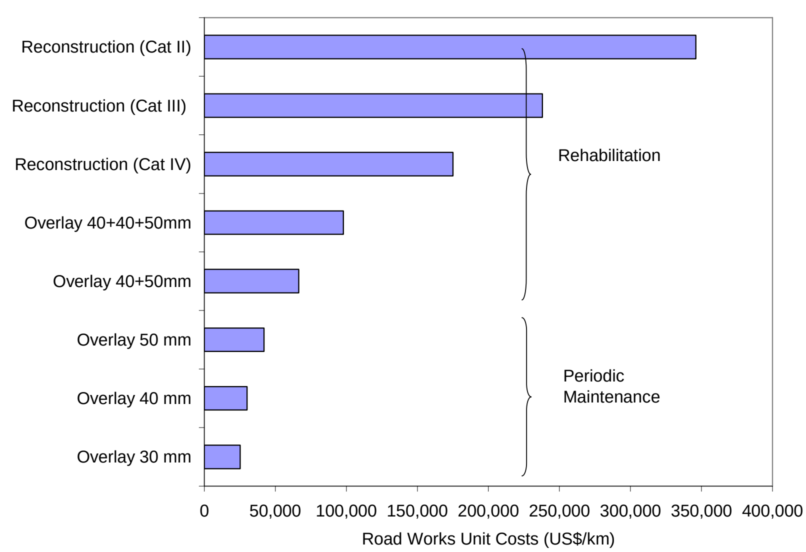
Table 4-5. Example of road work costs

Work Class	Type of road work	Predominant Work Activity	Code	Financial US$/m^2	Economic US$/m^2
Periodic Maintenance	Preventive Treatment	Slurry Seal 4 mm	P1	1.74	1.31
	Resurfacing with Surface Treatment	Single Surface Treatment 10 mm	P2	2.07	1.55
		Double Surface Treatment 25 mm	P3	4.22	3.17
	Resurfacing with Asphalt Concrete	Asphalt Overlay 30 mm	P4	7.68	5.76
		Asphalt Overlay 50 mm	P5	12.14	9.11
Rehabilitation	Strengthening	Asphalt Overlay 70 mm	R1	18.02	13.52
	Reconstruction	Reconstruction 50mm AC/200mm GB	R2	16.71	12.53

AC=Asphalt Concrete, GB=Granular Base

It is good practice to present a list of types of road work commonly performed in a given country (Table 3-6), following the road work classification given in the Road Costs Knowledge System (ROCKS) (available at http://worldbank.org/roadsoftwaretools/ and presented in Annex 2), to compare the unit costs of each type of road work in different countries. It is also good practice to present a bar chart of the unit costs of each type of road work to highlight the fact that rehabilitation costs are much higher than periodic maintenance costs. Figure 10 presents an example of this type of chart, showing different overlay and reconstruction options for a country in Asia.

Figure 4-2. Example of unit costs of road work



4.5 Defining project alternatives

The analyst has many options for defining the project alternatives in HDM-4 in relation to the *timing* of the road works. More specifically, HDM-4 allows for the definition of *condition-responsive* and *scheduled* project alternatives; for example, the maintenance schedule can be set up to execute an overlay when roughness reaches 4.0 IRI (condition-responsive) or to execute an overlay every 15 years (scheduled).

Table 4-6 presents an example of condition-responsive and scheduled project alternatives. Purely condition-responsive or purely scheduled project alternatives are not recommended because: (i) the interval between roads works should change over time on account of traffic growth; (ii) in the course of an evaluation period, the same types of road work typically should not be repeated (for example, if one defines an alternative as 100 mm overlay when roughness reaches 4.0 IRI, the first overlay of 100 mm may be reasonable if the road needs strengthening, but another overlay of 100 mm as a second capital type of work may be unreasonable).

Table 4-6. Condition-responsive and scheduled alternatives

Type of Project Alternative (timing)	Project Alternatives
Condition-Responsive	Execute Single Surface Treatment at 5% cracking Execute Single Surface Treatment at 10% cracking Execute Single Surface Treatment at 15% cracking Execute Asphalt Overlay 50 mm at IRI = 3.5 m/km Execute Asphalt Overlay 50 mm at IRI = 4.0 m/km Execute Asphalt Overlay 50 mm at 4.5 IRI Execute Asphalt Overlay 70 mm at 3.5 IRI Execute Asphalt Overlay 70 mm at 4.0 IRI Execute Asphalt Overlay 70 mm at 4.5 IRI
Scheduled	Execute Single Surface Treatment every 5 years Execute Single Surface Treatment every 9 years Execute Single Surface Treatment every 12 years Execute Asphalt Overlay 50 mm every 10 years Execute Asphalt Overlay 50 mm every 15 years Execute Asphalt Overlay 50 mm every 20 years Execute Asphalt Overlay 70 mm every 10 years Execute Asphalt Overlay 70 mm every 15 years Execute Asphalt Overlay 70 mm every 20 years

The methodology proposed in this paper calls for an alternative way of defining project alternatives, which consists of first identifying the possible types of road work in the country and next determining which types of road work to evaluate for each road class as a function of its traffic load, condition and other specific characteristics. For example, having identified the possible road works given in Table 4-5, the types of road work selected could be: (i) preventive treatment or surface treatment resurfacing for roads in *good* condition, (ii) surface treatment resurfacing or asphalt concrete resurfacing for roads in *fair* condition, and (iii) strengthening or reconstruction works for roads in *poor* condition.

It is important that the selected types of road work per road class be feasible from a technical point of view, yielding a reasonable design life, to produce realistic results. Each road work has a different *design life* estimated by the HDM-4 Model, for example, HDM-4 could estimate that a surface treatment will last eight years, a 50mm overlay will last 15 years and a 70mm overlay will last 20 years. The purpose of the evaluation is to identify a recommended type of road work for each road class, which translates to a recommended design life and level of investment, based on the road condition, traffic characteristics and the network's budget constraints. For example, even if a 70mm overlay gives the longest design life, maybe under budget constraints the recommended road work is a 50mm overlay with a shorter but still reasonable design life. It would be unrealistic and not advisable to evaluate a 50mm overlay if the resulting design life is too short and impractical.

Under the methodology proposed in this paper, project alternatives are defined so that a given initial *capital* road work is scheduled in a given calendar year, followed by a condition-responsive maintenance standard that keeps the road in good condition after the initial capital road work is executed. Typically, two to four road works are evaluated per road class and the HDM-4 analyst schedules them to be executed in different alternative calendar years.

Table 4-7 presents an example of the definition of project alternatives following the proposed methodology. In this example, a set of project alternatives are defined per road condition category; in a more comprehensive study, the project alternatives could also have been differentiated by traffic level. In this example, for roads in good condition, slurry seals and single surface treatments are being scheduled in 2007 or 2008 or 2009 or 2010. If these good condition roads do not require these road works so soon, another option could have been to postpone these works, for example, scheduling the road works in 2009 or 2010 or 2011 or 2012 for the good condition roads. In this example, for roads in fair condition, 50 mm overlays are scheduled in 2007 or 2008 or 2009 or 2010. Considering that if one postpones the 50 mm overlay, a road might need a thicker overlay in the future, one could have improved the definition of project alternative by scheduling, for example, 50 mm overlay in 2007 or 60 mm overlay in 2008 or 70 mm overlay in 2009 or 80 mm overlay in 2010.

By defining the project alternatives in this way, reasonable combinations of road work and timing of road work are considered in the evaluation. HDM-4 only evaluates the project alternatives defined by the user; accordingly, a different combination that was *not* defined by the user could yield a higher NPV. Therefore, *the definition of the project alternatives is critical for a good evaluation*. One approach taken to ensure a sound definition of project alternatives is to perform first a preliminary evaluation that evaluates for each road class, all possible road works identified in the country, occurring in year 1, even if some of them don't make sense from a technical point of view. This evaluation indicates the economically optimal road work on each road class and what are the road works that are not economically justified, because of a negative NPV. This preliminary evaluation then serves as a guide to select the few road works that will be evaluated per road class, including their possible postponement. For example, one could select for a road class the road work with the highest NPV and the road work next up in road work cost and the two road works next down in road work costs.

The road works scheduled in different calendar years bring the road back to good condition. Therefore, after these road works are executed, a condition-responsive maintenance standard is activated that will keep the road in good condition over the rest of the evaluation period. This condition-responsive maintenance standard could include recurrent works (like routine maintenance, drainage works and patching) and, for example, a 50mm overlay when the roughness reaches 4.0 IRI. It would not be realistic to expect that the future periodic maintenance will take place only a few years after the first intervention. Consequently, a minimum reasonable interval in years should be defined between the initial intervention and the next periodic maintenance road work. The optimal condition-responsive maintenance standard to be used could vary by surface type and traffic level; its definition can therefore be the product of a separate HDM-4 study designed to determine the country's optimal maintenance standard for different road classes in good condition, for example, analyzing different condition-responsive maintenance standards with different overlay-thickness and roughness trigger thresholds. In the proposed methodology, when a specific road work is not scheduled in year 1, then one also needs to specify the maintenance standard that will be implemented the years prior to the execution of the road work, which typically includes only recurrent maintenance works.

Table 4-7. Schedule of first intervention alternatives

	Project alternative	
Road Condition	Code	Description (First Road Work)
Good Condition	O1Y1	Execute Slurry Seal in 2007
	O1Y2	Execute Slurry Seal in 2008
	O1Y3	Execute Slurry Seal in 2009
	O1Y4	Execute Slurry Seal in 20010
	O2Y1	Execute Single Surface Treatment in 2007
	O2Y2	Execute Single Surface Treatment in 2008
	O2Y3	Execute Single Surface Treatment in 2009
	O2Y4	Execute Single Surface Treatment in 2010
Fair Condition	O2Y1	Execute Single Surface Treatment in 2007
	O2Y2	Execute Single Surface Treatment in 2008
	O2Y3	Execute Single Surface Treatment in 2009
	O2Y4	Execute Single Surface Treatment in 2010
	O5Y1	Execute Asphalt Overlay 50 mm in 2007
	O5Y2	Execute Asphalt Overlay 50 mm in 2008
	O5Y3	Execute Asphalt Overlay 50 mm in 2009
	O5Y4	Execute Asphalt Overlay 50 mm in 2010
Poor Condition	O6Y1	Execute Asphalt Overlay 70 mm in 2007
	O6Y2	Execute Asphalt Overlay 70 mm in 2008
	O6Y3	Execute Asphalt Overlay 70 mm in 2009
	O6Y4	Execute Asphalt Overlay 70 mm in 2010
	O7Y1	Execute Reconstruction in 2007
	O7Y2	Execute Reconstruction in 2008
	O7Y3	Execute Reconstruction in 2009
	O7Y4	Execute Reconstruction in 2010

Project alternatives include annual *routine* maintenance and patching during the evaluation period and a condition-responsive 50 mm overlay at 4.0 IRI after the initial capital road work.

A limitation of HDM-4 is the fact that the HDM-4 budget optimization using the EBM-32 algorithm cannot evaluate more than 400 different road classes and 17 project alternatives per road class. The challenge then is to define the road classes and project alternatives within these constraints. If these limits are exceeded, HDM-4 performs the budget optimization with a less precise algorithm. To remain within the 17 project alternatives per road class and to maximize the number of road works evaluated per road class, one typically considers one of the following options: (i) schedule four possible road works in years 1, 2, 3 or 4 or three possible road works in years 1, 2, 3, 4 or 5 (short-term evaluation to identify annual program); (ii) schedule four possible road works in years 1, 3, 5 or 7 (medium-term evaluation to identify biannual program); or (iii) schedule two possible road works in years 1, 2, 3, 4, 5, 6, 7 or 8. That way, the total number of project alternatives is 15 or 16 and the 16th or 17th alternative is reserved for the "without project –alternative".

The model compares the different project alternatives with a "without project alternative" that should represent a "do the minimum scenario", not a "do nothing scenario". The proposed methodology typically defines the "without project alternative" for bituminous roads to include recurrent works (for example, routine maintenance, drainage works and patching) and a condition-responsive reconstruction, triggered when the road is in poor condition (for example at 8 to 10 IRI), including an extra condition ensuring that the reconstruction will not be done during the first six to 12 years of the evaluation period—to avoid having a reconstruction done during the planning period in the "do the minimum scenario".

> If one needs to show the consequences of doing nothing, one can include in the evaluation a project alternative that represents doing nothing over the evaluation period (or doing just routine maintenance and patching), but this alternative should be considered a new project alternative and *not* the "without project alternative".

4.6 Defining project alternatives' names

HDM-4 produces many output results for each project alternative and evaluation year. To make it easier to explore the results, it is fundamental in the proposed methodology to name each project alternative systematically. It is recommended that the scheduled road work code (2 characters), followed by the timing of the scheduled road work (2 characters), be put at the beginning of the project alternative's name, making it easier to identify the solution of each road class just by looking at the alternative's name. For example, if one project alternative would apply a slurry seal in 2009, the project alternative's name could be:

- "O1Y3 - Slurry Seal in 2009", which indicates that the solution is to perform road work "O1" (Slurry Seal) in year 3 of the evaluation period "Y3"; or
- "O109 - Slurry Seal in 2009", which indicates that the solution is to perform road work "O1" (Slurry Seal) in year 2009 "09"; or
- "SSY3 - Slurry Seal in 2009", which indicates that the solution is to perform a slurry seal "SS" in year 3 of the evaluation period "Y3".

The advantage of naming the project alternatives this way is that once we get the HDM-4 results into Excel, the results may be summarized using Excel pivot tables. For example, Table 4-8 presents the selected project alternatives for some road classes. In this case, one could easily compute in Excel the costs and NPV distribution per road work type and year by extracting the road work code and the year code from the project alternatives' names and using Excel pivot tables.

Table 4-8. Example of names for project alternatives

Road Class	Project Alternative	Cost (m US$)	NPV (m US$)
O2AY	O1Y1 -Reseal 12 mm in 2001	0.08	0.4
O5BX	O3Y1 - Overlay 80 mm in 2001	1.64	6.63
T3CX	O2Y2 - Overlay 50 mm in 2002	1.96	5.45
O2CZ	O3Y2 - Overlay 80 mm in 2002	0.43	1.11
T2AZ	O1Y3 - Reseal 12 mm in 2003	0.01	0.02
O2BY	O3Y3 - Overlay 80 mm in 2003	0.27	0.74

4.7 Defining vehicle fleet characteristics and road user costs

HDM-4 estimates the benefits to society in terms of reduced costs to road users; therefore, economic road user costs are characterized for a given country as a function of the vehicle fleet unit costs, utilization and characteristics, and road characteristics. Table 4-9 presents a sample of the vehicle fleet data required by HDM-4.

Table 4-9. Example of vehicle fleet data

	Medium Car	Light Truck	Medium Truck	Heavy Truck	Articulated Truck	Medium Bus
Economic Unit Costs						
New Vehicle Cost (US$/vehicle)	13,000	30,000	47,000	75,000	104,000	86,000
New Tire Cost (US$/tire)	58.00	164.00	275.00	319.00	343.00	278.00
Fuel Cost (US$/liter)	0.38	0.32	0.32	0.32	0.32	0.32
Lubricant Cost (US$/liter)	2.90	2.90	2.90	2.90	2.90	2.90
Maintenance Labor Cost (US$/hour)	5.00	5.24	5.86	5.77	6.60	5.17
Crew Cost (US$/hour)	0.67	5.29	5.29	5.79	6.11	4.94
Overhead (US$/year)	94	81	1716	2222	12084	267
Interest Rate (%)	12	12	12	12	12	12
Working Passenger Time (US$/hour)	2.20	0.80	0.80	0.80	0.80	0.80
Non-working Passenger Time (US$/hour)	1.10	0.50	0.50	0.50	0.50	0.50
Cargo Delay (US$/hour)	0.00	0.07	0.07	0.07	0.07	0.00
Basic Characteristics						
Kilometers Driven per Year (km)	21000	48000	55000	74000	94000	85000
Hours Driven per Year (hr)	600	1300	1600	1900	2300	2000
Service Life (years)	11	10	11	11	11	9
Percent Private Use (%)	100.0	0.0	0.0	0.0	0.0	0.0
Number of Passengers (#)	2.0	1.0	1.0	1.0	1.0	30.0
Work Related Passenger-Trips (%)	75.0	0.0	0.0	0.0	0.0	75.0
Gross Vehicle Weight (tons)	1.2	4.6	10.1	20.0	35.6	9.5

Key HDM-4 vehicle fleet attributes in bold

A road user costs sensitivity study has shown that the most responsive inputs to road user costs benefits are: (i) new vehicle cost, (ii) kilometers driven per year, (iii) service life, (iv) maintenance labor cost, (v) gross vehicle weight, (vi) fuel cost, (vii) new tire cost, (vii) number of passengers and (viii) passenger time cost.

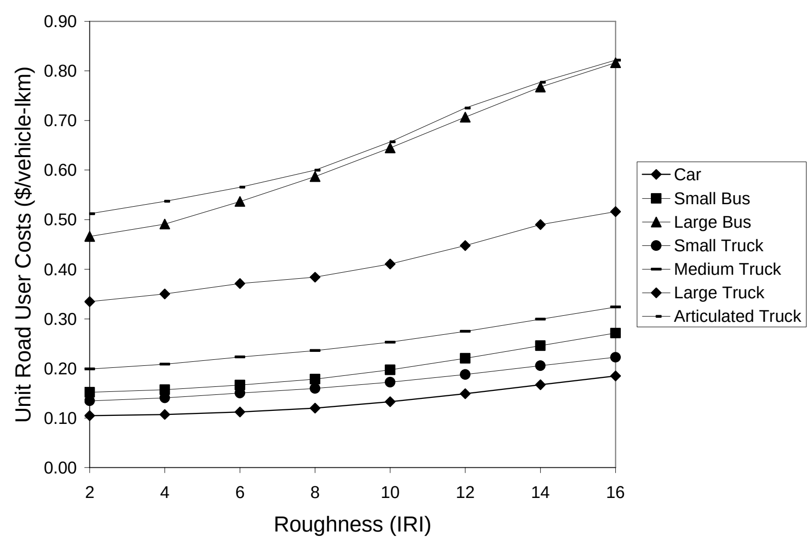
Table 4-10 presents an example of unit road user costs and composition computed by HDM-4 for a given country in Latin America. While this example only includes four-wheel motorized vehicles, HDM-4 can also be used to evaluate road user costs of motorcycles and non-motorized vehicles.

Table 4-10. Example of unit road user costs

Typical Road User Costs for Roughness = 2.0, US$/vehicle-km						
	Medium Car	Light Truck	Medium Truck	Heavy Truck	Articulated Truck	Medium Bus
Fuel & Lubricants	0.04	0.05	0.08	0.15	0.22	0.07
Tires	0.00	0.01	0.02	0.03	0.06	0.02
Maintenance	0.04	0.09	0.16	0.26	0.40	0.13
Crew	0.00	0.06	0.06	0.07	0.06	0.05
Depreciation & Interest	0.06	0.07	0.08	0.10	0.11	0.12
Time	0.04	0.01	0.01	0.01	0.01	0.24
Total	0.18	0.29	0.40	0.62	0.87	0.64

It is good practice to present the sensitivity of unit road user costs to roughness. For example, Figure 4-3 shows the sensitivity for seven vehicle types, with roughness varying from a paved road in good condition (2 IRI, m/km) to a paved road in extremely poor condition (16 IRI, m/km).

Figure 4-3. Example of unit road user costs sensitivity



4.8 HDM-4 calibration

Calibration of HDM-4 focuses on adjusting the road user effects—comprised of vehicle operating costs and travel time—and the road deterioration and works effects. It is recommended that at least a

Level 1 calibration of the model be performed, which determines the values of required basic input parameters, adopts many default values, and calibrates the most sensitive parameters with best estimates, desk studies or minimal field surveys. If possible a Level 2 calibration should be performed that uses direct measures of local condition to verify and adjust the predicted capability of the model. It requires a higher degree of data collection and precision than in a level 1 calibration, and extends the scope. One should refer to Volume 5 of the HDM-4 documentation for information on calibrating the model and the sensitivity of the main input parameters.

4.9 Performing budget constraints optimization

The strategic analysis is done to estimate the budget requirement for a given planning period. Typically the planning period is defined as the initial three to six years of the evaluation period, depending on the country's budgeting process. It is recommended that the evaluation period be two to three times the planning period, to be able to capture the future repercussions of budget constraints during the planning period and because HDM-4 does not take into account that the condition of the roads will be different at the end of the evaluation period. Typically, the evaluation period is set to 20 years, also in part because the HDM-4 budget optimization using the EBM-32 algorithm is limited to a 20-year evaluation period.

The definition of the project alternatives as proposed in this paper includes the scheduling of road work in specific years. Therefore, it is important that the initial road works be scheduled during the planning period and that the future condition-responsive road works not be executed during the planning period. It is also recommended that the reconstructions of the "without project alternative" not be executed during the planning period either.

HDM-4 evaluates each road class and identifies the project alternative that maximizes the NPV of the road class. The aggregation of the results for all road classes represents the *theoretical* unconstrained budget scenario. Typically the unconstrained budget scenario will have a road work pattern that has road work expenditures concentrated in the first few years. While this solution does maximize the network NPV, it is difficult to implement from a practical point of view because the flow of expenditures is not evenly distributed over the years.

The first step when performing a budget constraints optimization is therefore to find a *practical* unconstrained budget scenario, in which the road expenditures are by and large equally distributed during the planning period and the NPV is maximized. First one finds the HDM-4 unconstrained budget scenario and the total expenditures needed during the planning period, for example the first five years of the evaluation period. Next one imposes a budget constraint for each year of the planning period, equal to the total expenditures found before, divided by the number of years in the planning period, and a large budget for the rest of the evaluation period. It is assumed there will be no budget constraints after the planning period. This does not cause substantial loss in network NPV.

An illustration should clarify the procedure outlined above. In Table 4-11, the planning period is 2006 to 2010, and the road works needed in this period under the "unconstrained budget scenario" amount to US$337 million, of which US$194 million are concentrated in 2006. The *practical* unconstrained budget scenario (100 percent) was computed by applying to HDM-4 a budget constraint of US$67 million per year (337 divided by 5) from 2006 to 2010 and an unlimited budget from 2011 to 2025. The practical unconstrained budget scenario yields slightly less expenditures and a slightly lower network NPV compared to the unconstrained budget scenario, but is easier to implement.

Table 4-11. Example of comparison of road agency's financial costs

	Scenario Unconstrained Budget	Scenario 100% 60 M US$/year	Scenario 75% 49 M US$/year	Scenario 50% 34 M US$/year	Scenario 25% 17 M US$/year
Year	Total Financial Road Agency Capital Costs (M US$)				
2006	194	67	52	35	17
2007	3	67	52	35	17
2008	0	61	45	33	17
2008	1	52	45	35	17
2010	138	54	53	31	17
2006-2010	337	301	246	168	87
2011-2025	128	174	248	435	584
Period	Annual Financial Road Agency Capital Costs (M US$/year)				
2006-2010	67	60	49	34	17
2011-2025	9	12	17	29	39

The second step is to evaluate other budget scenarios with lower expenditures during the planning period, but keeping unconstrained the expenditures after the planning period. In Table 4-11, for example, three other scenarios were evaluated: US$49 million, US$34 million and US$17 million per year, which represent roughly 75 percent, 50 percent and 25 percent respectively of the practical unconstrained expenditures.

5 SUPPORT FOR PROGRAMMING OF ROAD WORKS

The results of the strategic planning study, for a given budget scenario, can be related to homogeneous road sections to support the decision making process on programming of road works per homogeneous road sections, provided the strategic planning evaluation was based on a network database of road information per homogenous road sections. The results per road class are related to the individual road sections by the road class identification code that should be added to the road sections database, as shown in Figure 5-1.

Figure 5-1. Example of the relationship between road sections and road classes

Road Sections Database

Road Section	Length (km)	Road Class
………………..	**9.3**	O2AY
………….	**21.5**	O2AY
.		
………….	**35.4**	O2AY
……………	15.1	O5BX
……..	1	O3BY
.		
………..	30.9	T3CX
……	5	O2CZ
…..	10.7	T4BX
…..	0.8	T2AZ
…….	4.6	O2BY

Relation

Matrix of Road Classes

Road Class	Length (km)	Results per Road Class	
O2AY	**66.2**		
O2BY	..	…	…
O3BY	..		
O5BX	..	…	..
T2AZ	..	..	..
T3CX	..	.. …	
T4BX	..		

Once the strategic evaluation results are related to the homogeneous road sections, one can present per road section: (i) section name and basic road characteristics, (ii) recommended road work (overly, reseal, etc.), (iii) the timing (year) of the recommended road work, (iv) the financial cost of performing the road work in that year, (v) the economic benefits of performing the road work (NPV), and (vi) a priority index (NPV per road work cost) to sort the sections by economic priority.

Table 5-1 presents a typical useful table for programming of works. In this case, the financial cost and the NPV are for the road section and not the total of the road class; therefore, one has to compute the road section financial cost and NPV, adopting the same financial cost and NPV per km of the corresponding road class results.

Table 5-1. Example of programming of works

Road Section	Length (km)	Width (m)	Traffic (AADT)	Rough. (IRI)	Road Class	Recommended Road Work	Year	Cost (M US$)	NPV (M US$)	NPV/ Cost
Villanueva - San Manuel	9.3	7.9	1333	3.2	O2AY	Reseal 12 mm	2001	0.08	0.40	4.73
.										
Occidente – El Portillo	35.4	7.3	1521	2.9	O2AY	Reseal 12 mm	2001	0.32	1.52	4.73
Acceso a Guaimaca	1.0	6.7	2772	4.2	O3BY	Overlay 80 mm	2001	0.08	0.30	3.82
.										
Alto Verde – Coyolito	30.9	7.3	1256	5.8	T3CX	Overlay 50 mm	2001	1.96	5.45	2.78
Las Tapias – Mateo	5.0	7.3	1384	5.3	O2CZ	Overlay 80 mm	2001	0.43	1.11	2.60
.										
Siguatepe. - Intibucca	10.7	7.5	2028	5.0	T4BX	Overlay 80 mm	2002	0.94	3.10	3.31
Acceso a Morazan	0.8	8.5	960	3.5	T2AZ	Reseal 12 mm	2002	0.01	0.02	2.73
Acceso a Trujillo	4.6	7.2	1437	4.9	O2BY	Overlay 80 mm	2002	0.27	0.74	2.71

The results of the economic evaluation, presented on Table 5-1, are a support element for the definition of a candidate annual or 2-3 year rolling program. A final definition of the program is typically done when the results of the economic evaluation are presented on different maps and other aspects are taken into account, such as contracts packaging, economic development priorities, balanced distribution of resources, and other strategic and political considerations. Once the final road works program is defined, each road section is submitted to a project-level economic evaluation with detailed project-level road characteristics data and refined cost estimates, complemented by a sensitivity analysis.

6 STRATEGIC PLANNING CHALLENGES

This type of network evaluation presents the following challenges:

- Estimation of the network length corresponding to each road class is sometimes complicated by the fact that traffic load, road condition data, and other road attributes typically are not collected by the same road agency unit nor at the same time; therefore, the available data cannot be easily combined and correlated.

- The characterization of each road class requires estimates of average values of roughness, cracking, traffic load, surface age, deflections, and the like, with the biggest challenge being the characterization of the road strength by the estimation of the road class average deflection or structural number. Deflections are costly and time-consuming to measure, and often there is a lack of knowledge regarding the network's history, surface layers, and thickness.

- Road agencies must make a commitment to the evaluation of different road work alternatives per road class. Generally, a road agency has a predefined technical solution matrix with one recommended solution per road class, based on current practices or purely on engineering considerations, without considering network budget constraints. The proposed methodology suggests that more than one road work should be evaluated per road class, always making sure that the proposed road works are feasible from an engineering point of view.

- The optimized economic evaluation (HDM-4) solution for a road class under network budget constraints could differ from a recommended solution considering only technical aspects and without considering network budget constraints; therefore, a road agency must commit to consider a network economic evaluation under a budget constraint optimization as a useful tool to better plan road works and to define the proper level of investments for each road class.

- Producing the types of graphs and tables presented in this paper is complicated because HDM-4 version 2.04 does not produce them automatically; therefore, they have to be produced in Excel, based on HDM-4 results collected from the HDM-4 reports or HDM-4 output files.

7 CONCLUSIONS

The HDM-4 model can be used for strategic planning of road works requiring different levels of input data, which can be measured or estimated by subjective evaluation. For planning purposes, an evaluation of road classes is typically conducted characterizing representative road classes with aggregate data on traffic load and road condition.

The key characteristics of the evaluation methodology presented in this paper are:

- The definition of project alternatives, for each road section or road class, by programming the first road work of the evaluation period in different calendar years, to be followed by a condition-responsive maintenance standard;
- The attempt to work within the HDM-4 version 2.04 limitation of evaluating up to 17 project alternatives for up to 400 road sections or road classes; and
- The need to manipulate the HDM-4 results in Excel to produce useful charts and summary tables.

The paper presents the methodology that is typically followed and a series of helpful sample graphs and tables used for planning and programming purposes that can be obtained from the HDM-4 evaluation, but are not produced automatically by HDM-4 version 2.04. HDM-4 is a very useful tool to help decision makers assess options related to the planning and/or programming of road works, helping them to evaluate different project alternatives and examine the impact of budget constraints on planning and programming.

The biggest challenges in carrying out a network HDM-4 evaluation are:

- Collecting the network data, which should not be too difficult as long as proper simplifications and assumptions are made;
- The limitations of HDM-4 2.04, particularly in the presentation of the evaluation results and the limits of the EBM-32 optimization; and
- The commitment of decision makers to the evaluation of different project alternatives per road class and to accepting the results of a network budget constraints optimization as a useful tool for better planning of road investments.

References

1. Highway Development and Management Model (HDM-4)
http://hdmglobal.com

2. World Bank Road Software Tools
http://worldbank.org/roadsoftwaretools/

ANNEX A. STRATEGY EVALUATION WITH HDM-4 VERSION 2.04

This appendix presents a case study of a strategy evaluation, using HDM-4 version 2.04, which shows the steps needed to perform the evaluation and gives some suggestions to make the evaluation more efficient. The HDM-4 workspace presented in this Annex is available for download at the http://worldbank.org/roadsoftwaretools/ website under "HDM-4 Version 2.0 WB Case Studies 1.0". The HDM-4 strategy name is "North Region Evaluation".

HDM-4 version 2.04 is the latest version of the HDM-4 software. The main software improvements of version 2.04 in relation to version 1.3 are:

- Sensitivity analysis at *project* level;
- Storage of different budget optimizations at *network* level;
- Output files in Microsoft Access format;
- New interface to define the intervention criteria of road works;
- More options to trigger road work;
- New alternative interface to define project alternatives;
- Input of traffic composition in addition to other road attributes when defining a road network;
- Definition of traffic growth sets;
- Calibration factors defined per road class and not per individual road section;
- New emission models;
- Calculation of the asset value of the roads; and
- Multi-criteria analysis.

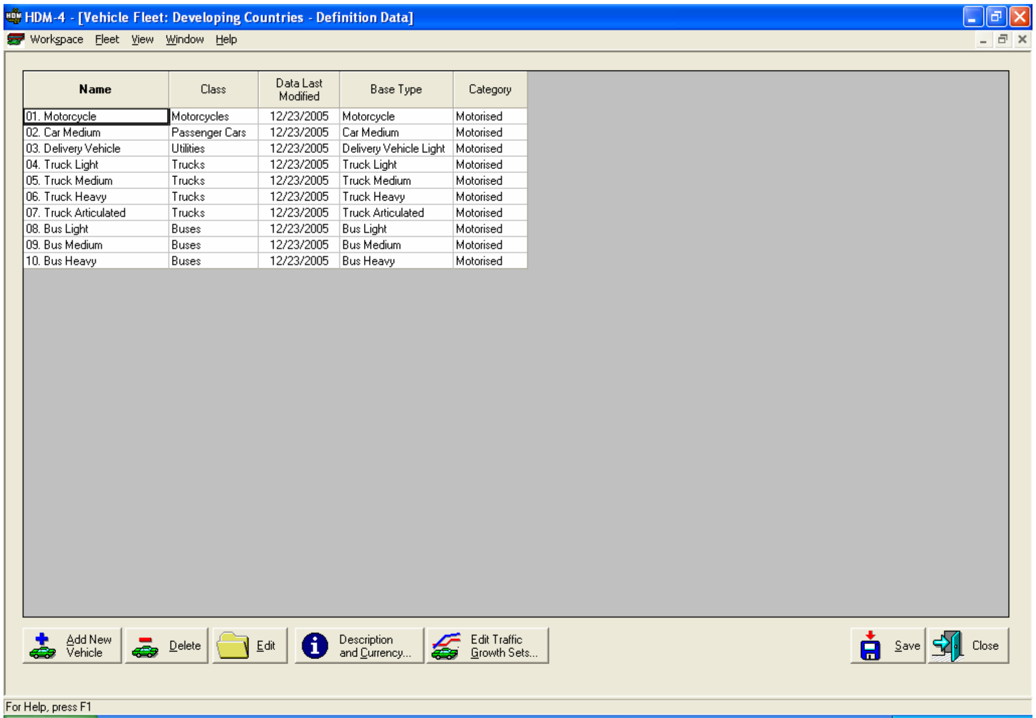
The evaluation steps are the following: (i) configure the HDM-4 workspace; (ii) define the vehicle fleet; (iii) define the road network classes; (iv) define maintenance standards; (v) define the strategy evaluation; (vi) specify project alternatives; (vii) generate the strategy; (viii) perform a budget constraints optimization; (ix) generate reports; and (x) explore the HDM-4 results.

Configure the HDM-4 Workspace

Configure the HDM-4 workspace with proper default values for the country. The process of configuration for a *network* is the same as for a *project*-level evaluation.

Define Vehicle Fleet

Define the vehicle fleet—in terms of the most common vehicle types in the country and different traffic growth scenarios. Typically only one vehicle fleet is defined for all roads in the country. The vehicle types defined should be preferable to the ones adopted in the traffic-counting locations. In the example below, a total of 10 motorized vehicle types were defined in the vehicle fleet. The vehicle names start with a number so that they can be sorted by logical order later. The process of characterizing the vehicle fleet is the same as for a project-level evaluation.



Define Road Network Classes

Define the road network that contains the road classes that will be evaluated. For example, in the road network below, 50 possible road classes were defined in terms of surface type, traffic load and condition. Each road class is identified by an ID code and a description. In this case, the *first* letter of the ID code refers to the surface type (**C** for Asphalt **C**oncrete and **S** for **S**urface Treatment roads), the *second* letter to the traffic level (1 to 5), and the *third* letter to the condition category (A to E).

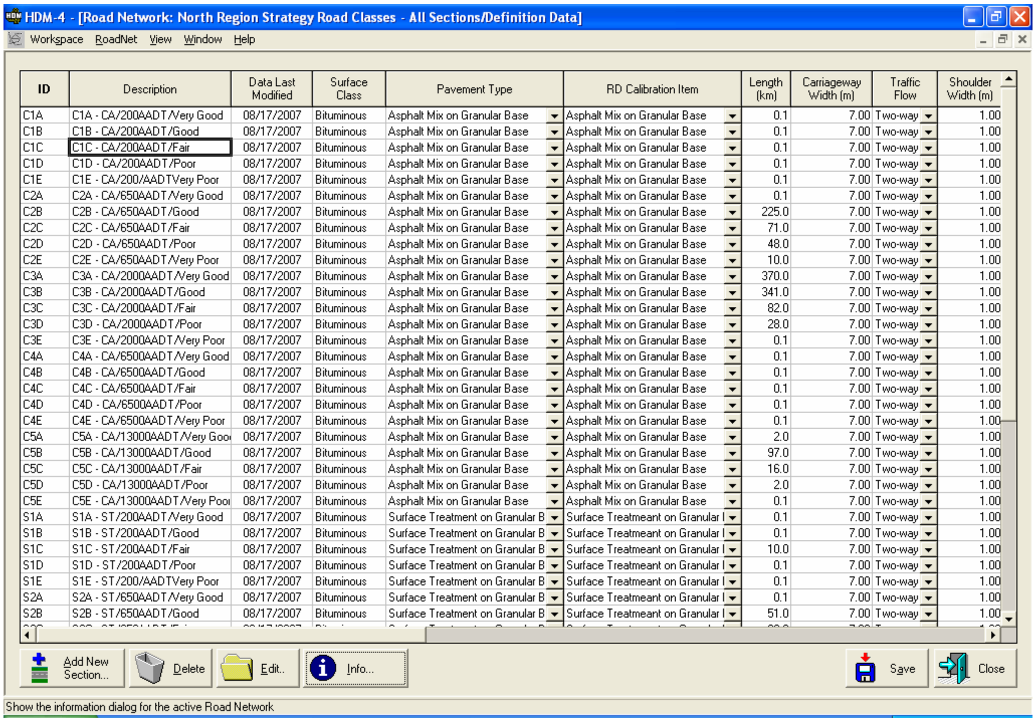
The *traffic levels* are:

1	< 300 AADT	Average AADT = 200
2	300-1000 AADT	Average AADT = 650
3	1000-3000 AADT	Average AADT = 2000
4	3000-10000 AADT	Average AADT = 6500
5	> 10000 AADT	Average AADT = 13000

The *condition categories* are:

A	Very Good	Roughness = 2 IRI	Damaged Area = 0%
B	Good	Roughness = 2 IRI	Damaged Area = 1%
C	Fair	Roughness = 4 IRI	Damaged Area = 15%
D	Poor	Roughness = 6 IRI	Damaged Area = 35%
E	Very Poor	Roughness = 8 IRI	Damaged Area = 55%

It is good practice to include the ID code of each road class to the left of the road class description so that later they can be sorted by logical order—either by ID code or description.



ID	Description	Data Last Modified	Surface Class	Pavement Type	RD Calibration Item	Length (km)	Carriageway Width (m)	Traffic Flow	Shoulder Width (m)
C1A	C1A - CA/200AADT/Very Good	08/17/2007	Bituminous	Asphalt Mix on Granular Base	Asphalt Mix on Granular Base	0.1	7.00	Two-way	1.00
C1B	C1B - CA/200AADT/Good	08/17/2007	Bituminous	Asphalt Mix on Granular Base	Asphalt Mix on Granular Base	0.1	7.00	Two-way	1.00
C1C	C1C - CA/200AADT/Fair	08/17/2007	Bituminous	Asphalt Mix on Granular Base	Asphalt Mix on Granular Base	0.1	7.00	Two-way	1.00
C1D	C1D - CA/200AADT/Poor	08/17/2007	Bituminous	Asphalt Mix on Granular Base	Asphalt Mix on Granular Base	0.1	7.00	Two-way	1.00
C1E	C1E - CA/200/AADTVery Poor	08/17/2007	Bituminous	Asphalt Mix on Granular Base	Asphalt Mix on Granular Base	0.1	7.00	Two-way	1.00
C2A	C2A - CA/650AADT/Very Good	08/17/2007	Bituminous	Asphalt Mix on Granular Base	Asphalt Mix on Granular Base	0.1	7.00	Two-way	1.00
C2B	C2B - CA/650AADT/Good	08/17/2007	Bituminous	Asphalt Mix on Granular Base	Asphalt Mix on Granular Base	225.0	7.00	Two-way	1.00
C2C	C2C - CA/650AADT/Fair	08/17/2007	Bituminous	Asphalt Mix on Granular Base	Asphalt Mix on Granular Base	71.0	7.00	Two-way	1.00
C2D	C2D - CA/650AADT/Poor	08/17/2007	Bituminous	Asphalt Mix on Granular Base	Asphalt Mix on Granular Base	48.0	7.00	Two-way	1.00
C2E	C2E - CA/650AADT/Very Poor	08/17/2007	Bituminous	Asphalt Mix on Granular Base	Asphalt Mix on Granular Base	10.0	7.00	Two-way	1.00
C3A	C3A - CA/2000AADT/Very Good	08/17/2007	Bituminous	Asphalt Mix on Granular Base	Asphalt Mix on Granular Base	370.0	7.00	Two-way	1.00
C3B	C3B - CA/2000AADT/Good	08/17/2007	Bituminous	Asphalt Mix on Granular Base	Asphalt Mix on Granular Base	341.0	7.00	Two-way	1.00
C3C	C3C - CA/2000AADT/Fair	08/17/2007	Bituminous	Asphalt Mix on Granular Base	Asphalt Mix on Granular Base	82.0	7.00	Two-way	1.00
C3D	C3D - CA/2000AADT/Poor	08/17/2007	Bituminous	Asphalt Mix on Granular Base	Asphalt Mix on Granular Base	28.0	7.00	Two-way	1.00
C3E	C3E - CA/2000AADT/Very Poor	08/17/2007	Bituminous	Asphalt Mix on Granular Base	Asphalt Mix on Granular Base	0.1	7.00	Two-way	1.00
C4A	C4A - CA/6500AADT/Very Good	08/17/2007	Bituminous	Asphalt Mix on Granular Base	Asphalt Mix on Granular Base	0.1	7.00	Two-way	1.00
C4B	C4B - CA/6500AADT/Good	08/17/2007	Bituminous	Asphalt Mix on Granular Base	Asphalt Mix on Granular Base	0.1	7.00	Two-way	1.00
C4C	C4C - CA/6500AADT/Fair	08/17/2007	Bituminous	Asphalt Mix on Granular Base	Asphalt Mix on Granular Base	0.1	7.00	Two-way	1.00
C4D	C4D - CA/6500AADT/Poor	08/17/2007	Bituminous	Asphalt Mix on Granular Base	Asphalt Mix on Granular Base	0.1	7.00	Two-way	1.00
C4E	C4E - CA/6500AADT/Very Poor	08/17/2007	Bituminous	Asphalt Mix on Granular Base	Asphalt Mix on Granular Base	0.1	7.00	Two-way	1.00
C5A	C5A - CA/13000AADT/Very Goo	08/17/2007	Bituminous	Asphalt Mix on Granular Base	Asphalt Mix on Granular Base	2.0	7.00	Two-way	1.00
C5B	C5B - CA/13000AADT/Good	08/17/2007	Bituminous	Asphalt Mix on Granular Base	Asphalt Mix on Granular Base	97.0	7.00	Two-way	1.00
C5C	C5C - CA/13000AADT/Fair	08/17/2007	Bituminous	Asphalt Mix on Granular Base	Asphalt Mix on Granular Base	16.0	7.00	Two-way	1.00
C5D	C5D - CA/13000AADT/Poor	08/17/2007	Bituminous	Asphalt Mix on Granular Base	Asphalt Mix on Granular Base	2.0	7.00	Two-way	1.00
C5E	C5E - CA/13000AADT/Very Poor	08/17/2007	Bituminous	Asphalt Mix on Granular Base	Asphalt Mix on Granular Base	0.1	7.00	Two-way	1.00
S1A	S1A - ST/200AADT/Very Good	08/17/2007	Bituminous	Surface Treatment on Granular B	Surface Treatmeant on Granular I	0.1	7.00	Two-way	1.00
S1B	S1B - ST/200AADT/Good	08/17/2007	Bituminous	Surface Treatment on Granular B	Surface Treatmeant on Granular I	0.1	7.00	Two-way	1.00
S1C	S1C - ST/200AADT/Fair	08/17/2007	Bituminous	Surface Treatment on Granular B	Surface Treatmeant on Granular I	10.0	7.00	Two-way	1.00
S1D	S1D - ST/200AADT/Poor	08/17/2007	Bituminous	Surface Treatment on Granular B	Surface Treatmeant on Granular I	0.1	7.00	Two-way	1.00
S1E	S1E - ST/200/AADTVery Poor	08/17/2007	Bituminous	Surface Treatment on Granular B	Surface Treatmeant on Granular I	0.1	7.00	Two-way	1.00
S2A	S2A - ST/650AADT/Very Good	08/17/2007	Bituminous	Surface Treatment on Granular B	Surface Treatmeant on Granular I	0.1	7.00	Two-way	1.00
S2B	S2B - ST/650AADT/Good	08/17/2007	Bituminous	Surface Treatment on Granular B	Surface Treatmeant on Granular I	51.0	7.00	Two-way	1.00

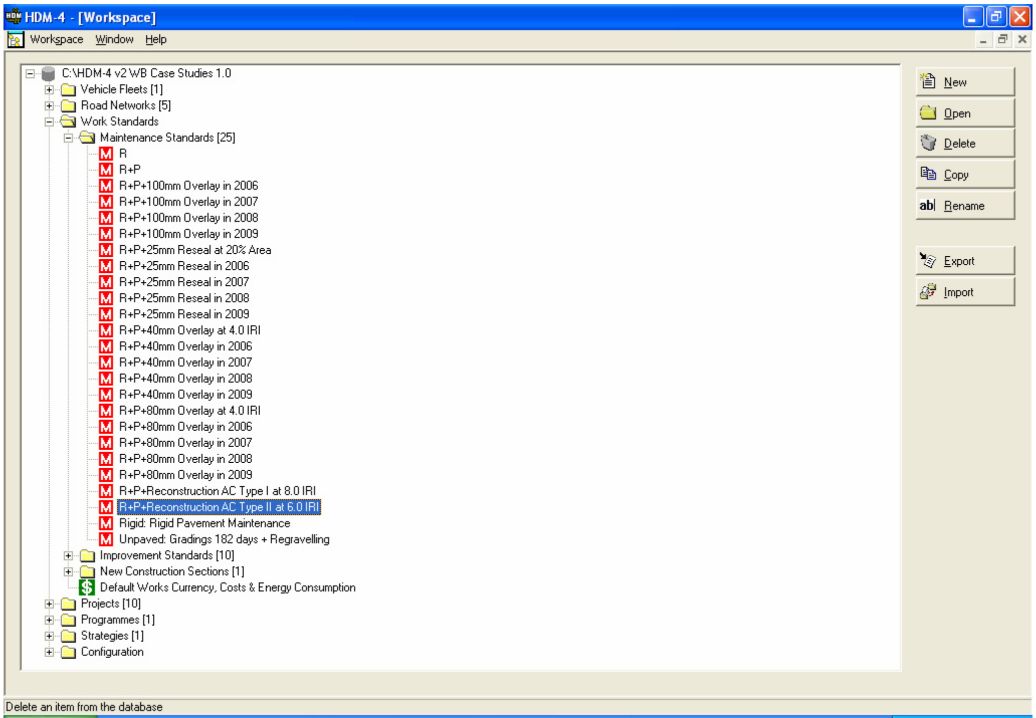
In this case, the total possible number of road classes is 50; consequently, 50 road classes have been defined, with average attributes of road geometry, pavement type, road condition, etc. Note, however, that the number of classes in the country with more than zero kilometers (of road length) will most likely be less than 50. The HDM-4 evaluation will therefore be done only on the road classes with more than zero kilometers. It is still good practice to define all possible road classes in the road network but to define the length of the road classes with zero kilometers as 0.1 km (as a zero-kilometer length is not a valid HDM-4 input). For the other road classes, the length is the sum of the length of network road sections with the same average characteristics of the road class. When defining the Strategy Analysis, the road classes with 0.1 km will not be selected. This way, if later the distribution of the network length varies, the network matrix will only need minor modifications.

The process of entering the road classes is the same as for a project-level evaluation; the only difference is that, conceptually, one is defining road *classes* and not road *sections*, which have a defined origin and destination. In this case study, all the road classes were defined using the aggregate default values of HDM-4 Version 2.04 and assuming that: (i) all road classes have a good compaction quality; (ii) all road classes have a good surface texture; (iii) all road classes have a v-shaped hard drain type; and (iv) the surface year of the road classes is 2005 for “very good”, 2000 for “good”, 1995 for “fair”, 1990 for “poor” and 1985 for “very poor condition”. In this case study, the evaluation period starts in 2006; therefore, the road condition data was defined for 2005.

Define Maintenance Standards

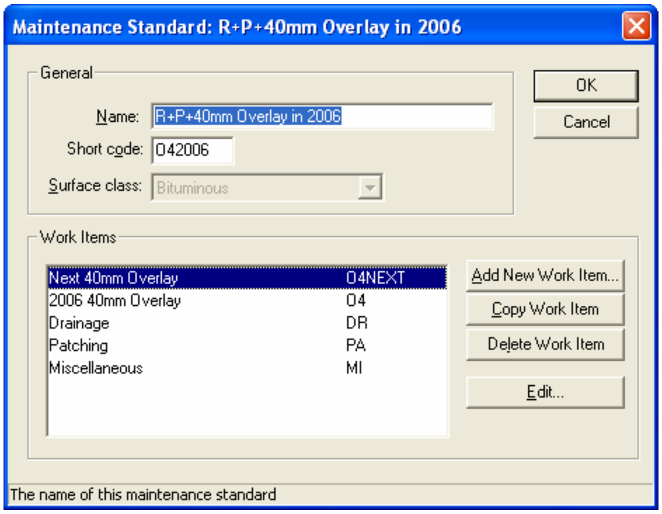
Define the maintenance standards to be used in the evaluation. First you define the possible capital road works (for periodic maintenance or rehabilitation) that could be executed in the country and then you define different maintenance standards, scheduling these different types of road work in different calendar years. For example, one has the following possible capital road works defined in the collection of maintenance standards given below:

Road Work	Economic Cost (US$/m2)	Financial Cost (US$/m2)
25 mm Reseal	3.2	4.0
40 mm Overlay	8.0	10.0
80 mm Overlay	14.4	18.0
100 mm Overlay	17.6	22.0
Reconstruction AC I	32.0	40.0

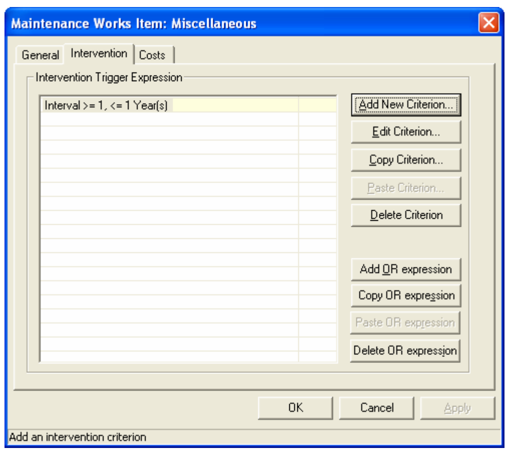


Each maintenance standard is given a name that should indicate the road work items that will be executed under the standard. For example, a standard named “R+P+40mm Overlay at 4.0 IRI” will execute routine maintenance (R) plus patching (P) every year plus a 40mm overlay when the road roughness reaches 4.0 IRI. 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

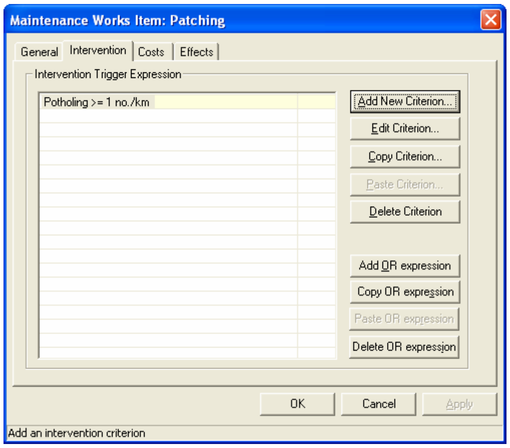


The item *"Miscellaneous"* represents the component of routine maintenance that does not affect the deterioration of the carriageway (for example, maintenance of vertical and horizontal signs). In this case, the miscellaneous activities are scheduled every year, as shown below.

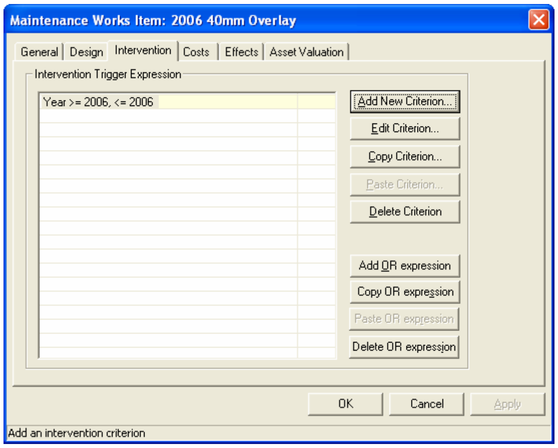


The item *"Drainage"* represents the component of routine maintenance that impacts the deterioration of the carriageway by affecting the drainage of the road (for example, cleaning culverts or mowing grass). In this case, the drainage activities are also scheduled every year.

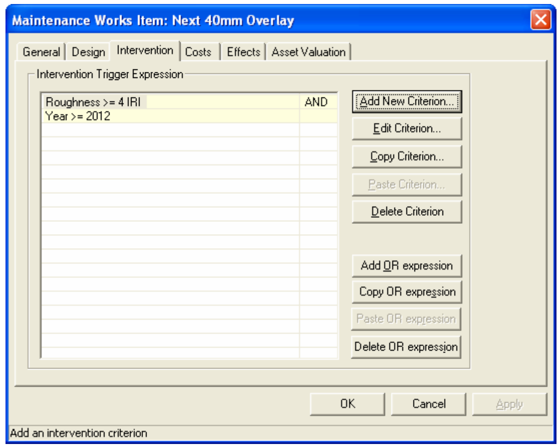
The item *"Patching"* represents the amount of pothole patching being done on the roads. In this case, all potholes will be patched every year. The intervention trigger expression is to patch the potholes when the number of potholes per km is greater than one.



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.



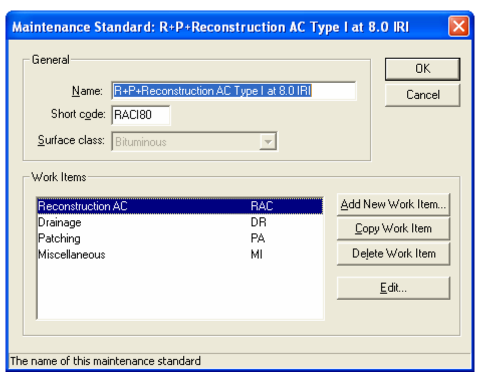
The item *"Next 40mm Overlay"* represents the future periodic maintenance road work (in this case an overlay) that will be done on the road, after the initial road work is executed. In this case, the next overlay is condition- responsive and is triggered when the road roughness reaches 4.0 IRI, as shown 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 (a minimum of 6 years is recommended between consecutive overlays).



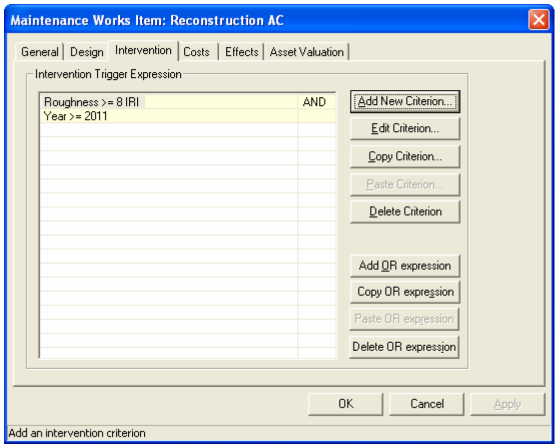
In this example, the following possible project alternatives were defined:

- 25 mm Reseal in 2006, 2007, 2008 or 2009
- 40 mm Overlay in 2006, 2007, 2008 or 2009
- 80 mm Overlay in 2006, 2007, 2008 or 2009
- 100 mm Overlay in 2006, 2007, 2008 or 2009

An important element of an economic evaluation is the definition of the "without project alternative" (or "base alternative"), which should represent the actions of the road agency over the 20-year evaluation period in case the project is not implemented. The base alternative should represent the "do the minimum scenario" and not the "do nothing scenario". In this example, the base alternative is named "R+P+Reconstruction AC Type I at 8.0 IRI" and is defined as executing routine maintenance (R) plus patching (P) every year over the evaluation period plus a reconstruction Type I when the road roughness reaches 8.0 IRI, as shown below.



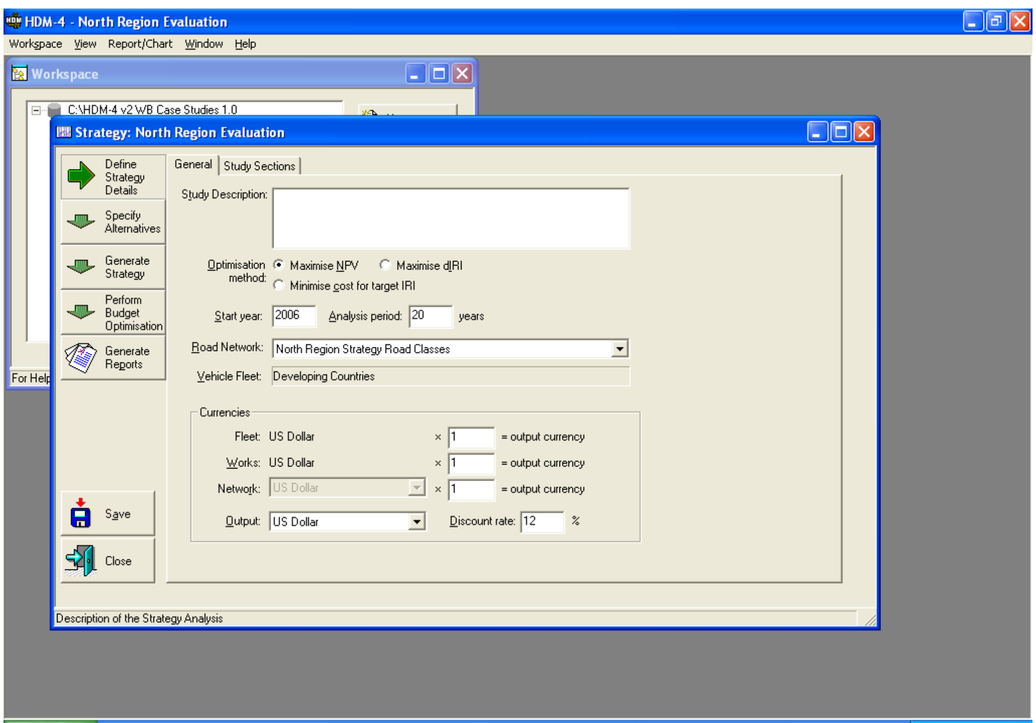
There could be different reconstruction options in the country (for example, different layer thickness, width and costs); therefore, a condition-responsive reconstruction "Type I" was defined, as shown below, which represents an asphalt concrete reconstruction. An additional criterion was added to avoid 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). One wants to avoid the reconstruction of the base alternative to appear during the planning period, that is, 2006 to 2009 in this case study.



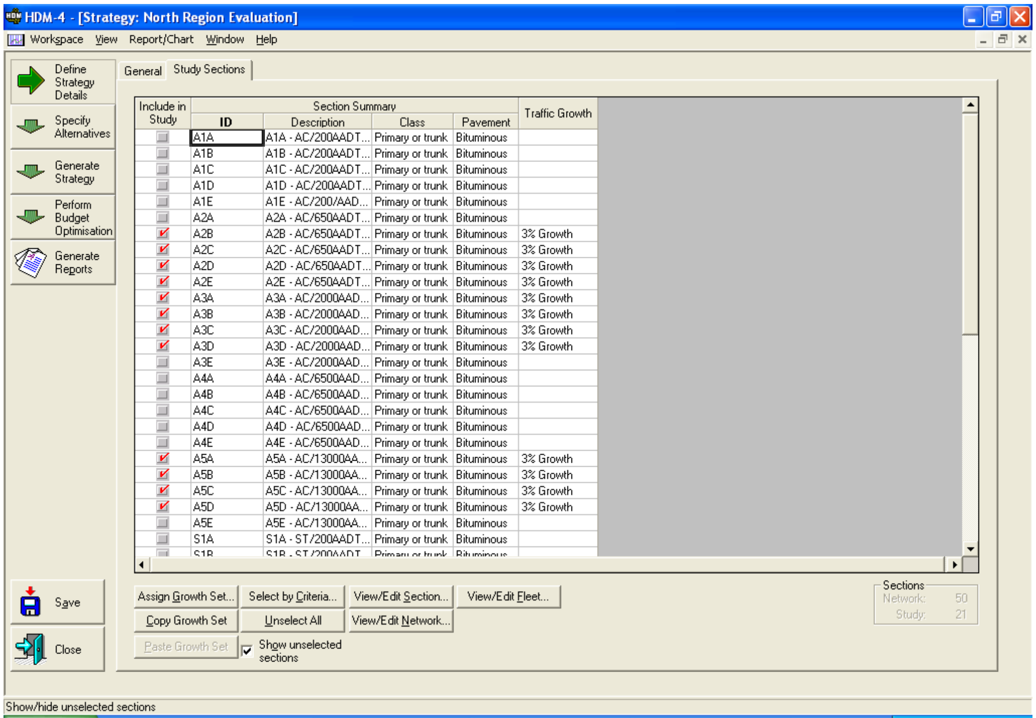
The definition of the work items' characteristics (general information, design, costs, effects, etc.) is the same as for a project-level evaluation.

Define Strategy Evaluation

Create a new strategy evaluation defining the *evaluation period* (in this example 20 years), the *start year* (in this example 2006), the *discount rate* (in this example 12 percent), and the *output currency*. Lastly, define the budget optimization method that should be set to Maximize NPV.



At the study sections tab, define the road classes that will be evaluated and the traffic growth forecast of each road class, as shown below. *Only the road classes with a length of more than 0.1 kilometers should be selected.*



Specify Alternatives

Define the project alternatives to be evaluated for each class, which should be a function of the condition and traffic load of each road class. For example:

Road in Very Good or Good Condition

25 mm Reseal	in 2006, 2007, 2008 or 2009

Road in Fair Condition

25 mm Reseal	in 2006, 2007, 2008 or 2009
40 mm Overlay	in 2006, 2007, 2008 or 2009
80 mm Overlay	in 2006, 2007, 2008 or 2009

Road in Poor Condition

80 mm Overlay	in 2006, 2007, 2008 or 2009
100 mm Overlay	in 2006, 2007, 2008 or 2009

Road in Very Poor Condition

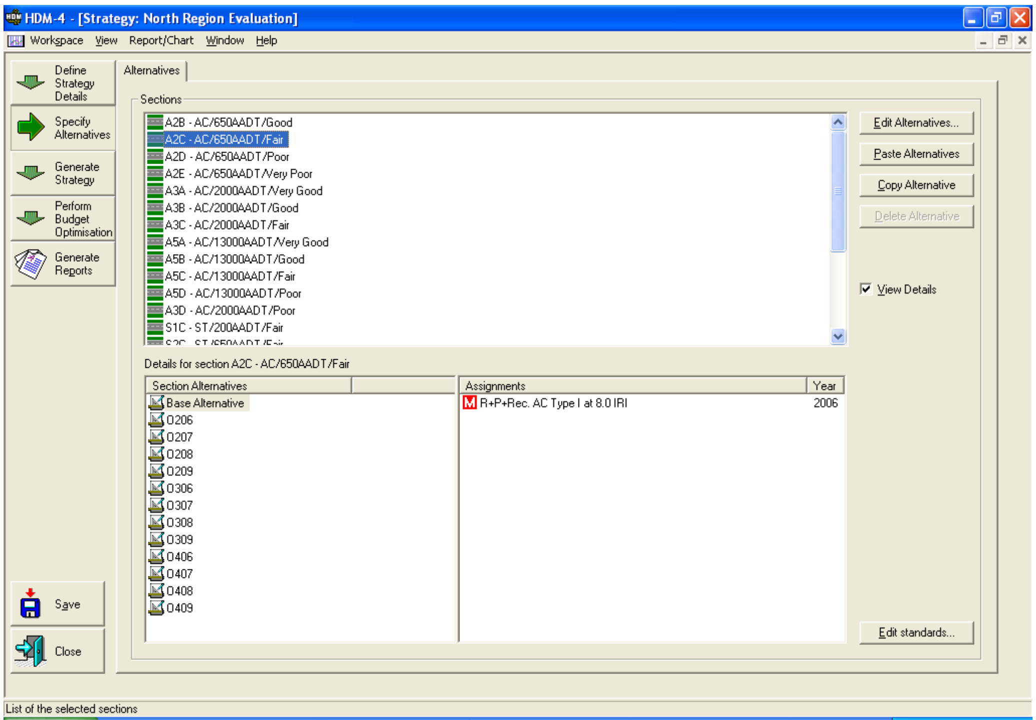
100 mm Overlay	in 2006, 2007, 2008 or 2009

Each type of capital road work is given an identification code of two characters, for example:

Road Work Code O1	12 mm Reseal
Road Work Code O2	25 mm Reseal
Road Work Code O3	40 mm Overlay
Road Work Code O4	80 mm Overlay
Road Work Code O5	100 mm Overlay

Each project alternative is given a name. In this example, the project alternative name is a four-character code, where the first two characters are the road work identification code (O1, O2, etc.) and the last two characters the scheduled year (06 for 2006, 07 for 2007, etc.). *The name of the base alternative cannot be changed*.

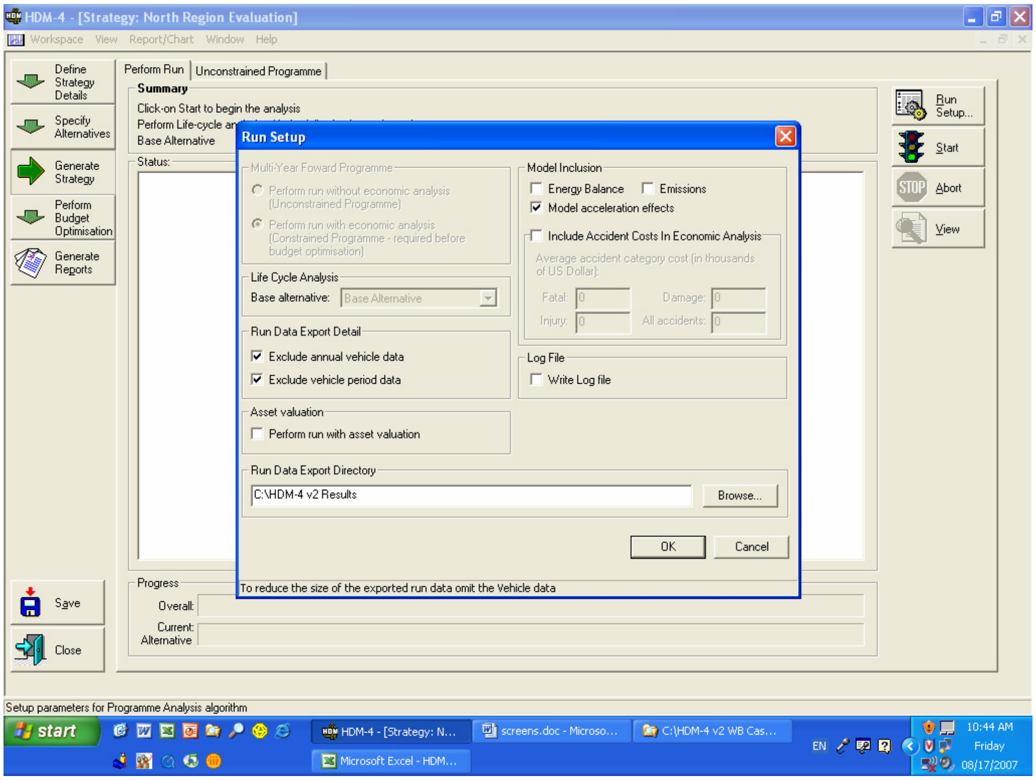
The screen below shows the project alternatives defined for the road class C2C (in fair condition), using the HDM-4 version 2.04 classic style for the specification of the project alternatives, which is preferred by the author. HDM-4 version 2.04 offers two styles to define the project alternatives—a classic style (similar to version 1.3 style), and a new style, introduced in version 2.0.



To each alternative corresponds a given maintenance standard effective from 2006.

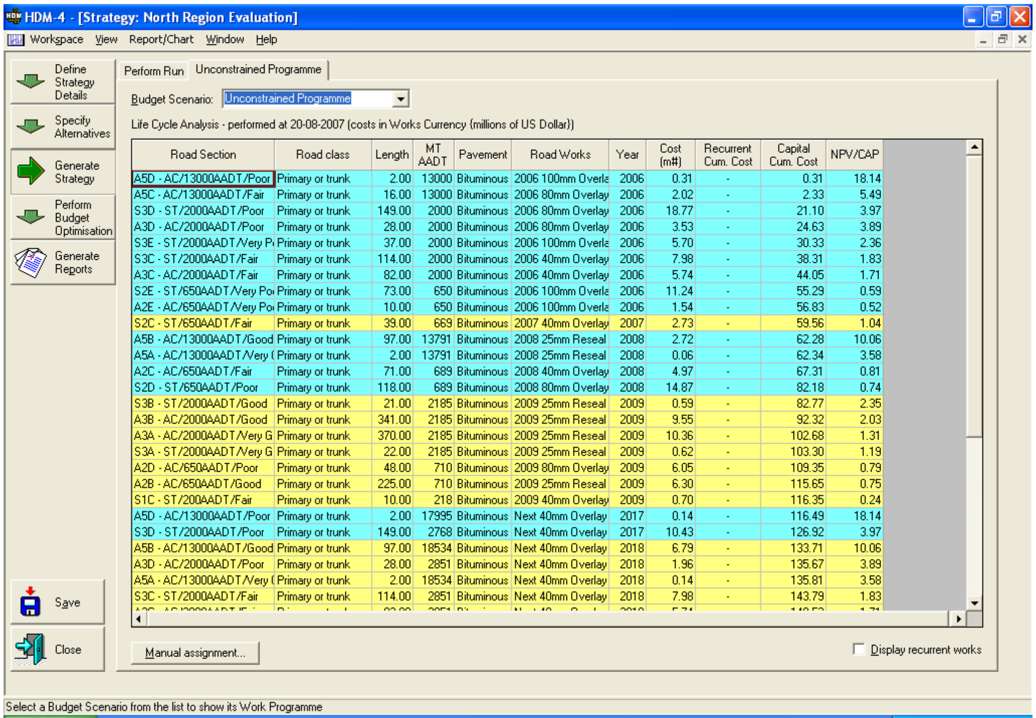
Generate Strategy

Define the Run Setup of the evaluation, excluding annual vehicle data, as shown below—to exclude from the output files the detailed road user cost outputs (fuel consumption, speeds, unit road user costs, etc.) otherwise computed by the model—to reduce the size of the output files and increase the speed of the calculations. At the Run Setup screen, one also defines the Run Data Export Directory, that is, the Windows folder where the output files should be placed.



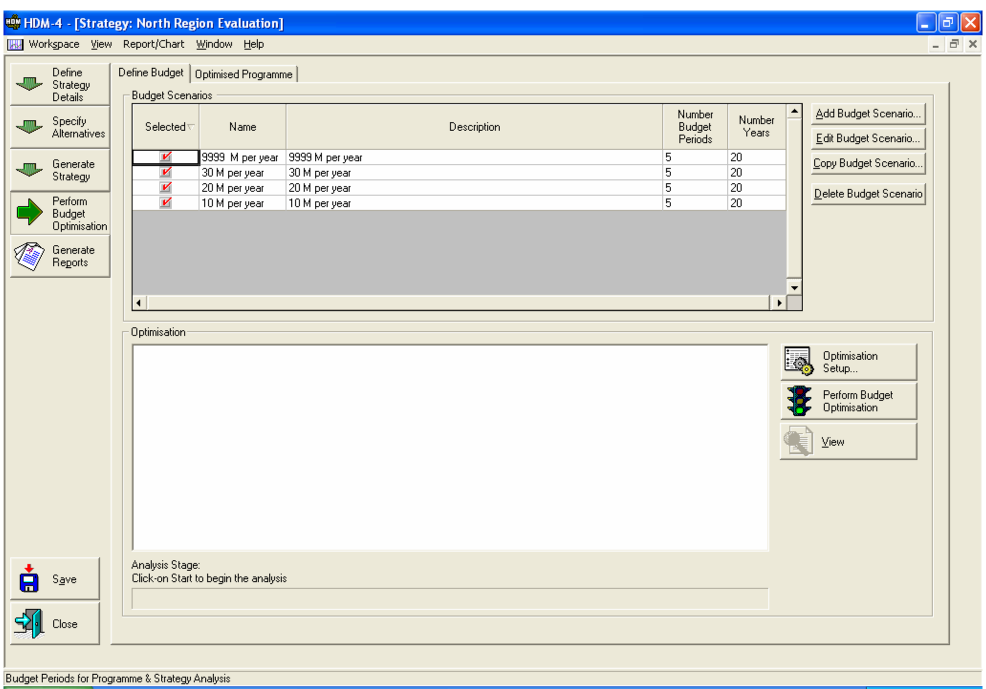
Once you press the Start button, the evaluation is performed and, if no input errors are found by HDM-4, you can view the resulting unconstrained program (on the right tab) that shows the road section name, length, traffic load, pavement type, type of road work, timing of the road work, financial cost of executing the road work in the scheduled year, capital cumulative road work costs, and the economic priority indicator NPV per capital cost. In the example below, it is worth noting that, under the "unconstrained budget scenario", (i) US$116.35 million are needed in cumulative terms from 2006 to 2009 and (ii) the annual distribution of the expenditures is not uniform (for example, US$55.83 million is needed in 2006 and only US$2.73 million is needed in 2007).

While this work program maximized the NPV of the network and therefore, in theory, is the optimal work program, it cannot be implemented due to the uneven distribution of expenditures over the years. Therefore, one needs to perform budget optimizations to (i) identify a work program that roughly distributes evenly the expenditures over the years, maximizing the NPV of the network, and corresponding to around US$116 million of total expenditures from 2006 to 2009 (unconstrained budget); and (ii) identify optimal work programs under budget constraints.



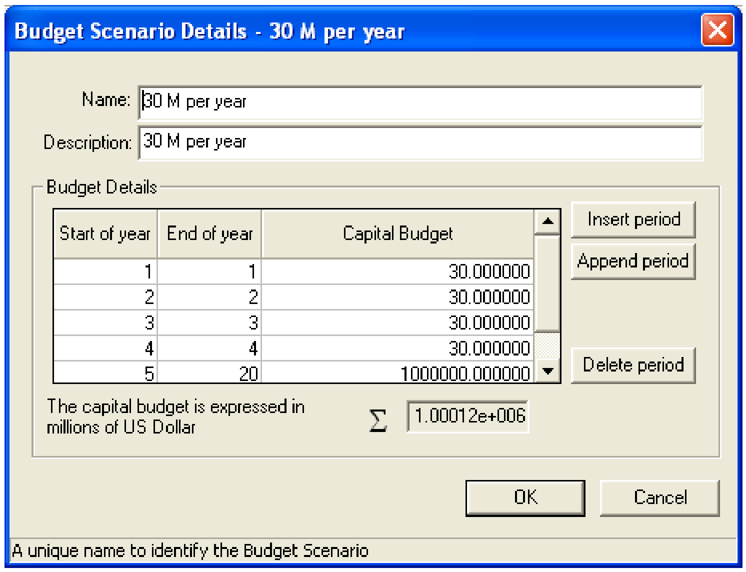
Perform Budget Optimization

Perform budget optimization by defining different budget scenarios and finding the optimal combination of project alternatives for each budget scenario, which is the one that maximizes the Net Present Value of the network. For example, one could define budget scenarios of 9,999, 30, 20 or 10 (in millions of US$) per year of expenditures during the planning period (2006 to 2009), as shown below.

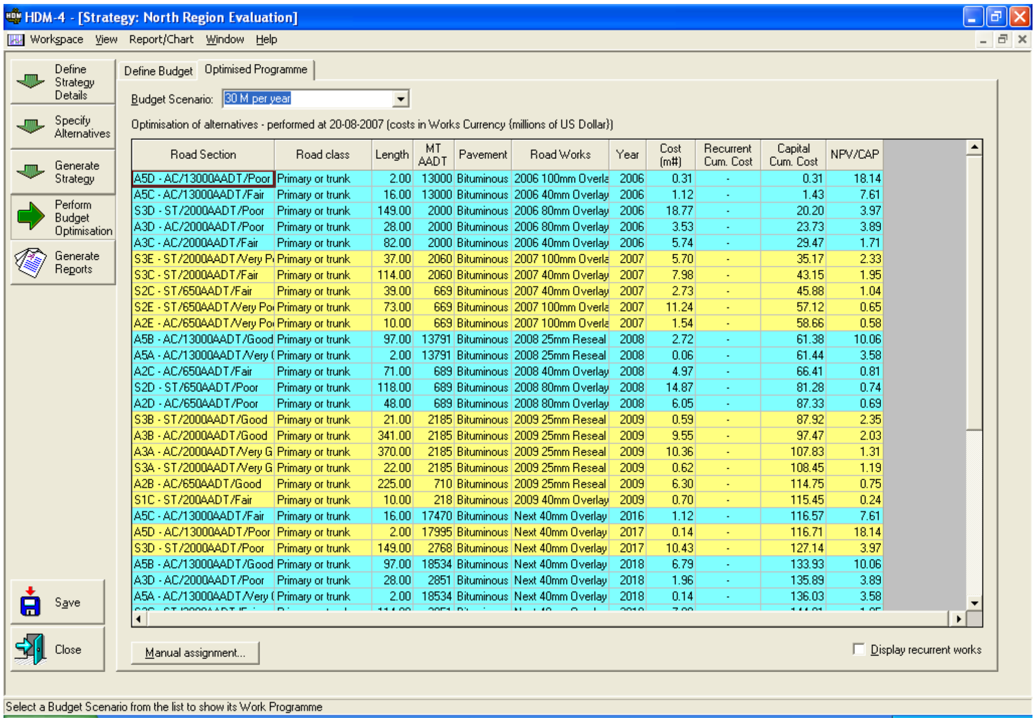


A budget of US$9,999 million per year represents the availability of a very high amount per year, defined to simulate the “without budget constraints scenario”. The US$30 million per year from 2006 to 2009 totals US$120 million from 2006 to 2009, which is more or less equivalent to the optimal expenditures of US$116.35 million under the without budget constraints scenario. Therefore, US$30 million per year represents a realistic work program (100 percent scenario), with total expenditures similar to the unconstrained budget scenario, but which is not realistic given the uneven distribution of resources.

The screen on the next page shows the definition of the US$30 million per year scenario. In this case study, the evaluation period (20 years) was divided into 5 budget periods (Year 1, Year 2, Year 3, Year 4 and Years 5 to 20), years 1 to 4 representing the planning period. In this case, the budget period after the planning period, from years 5 to 20, was left unconstrained with a very high amount of resources available (US$1,000,000 million).

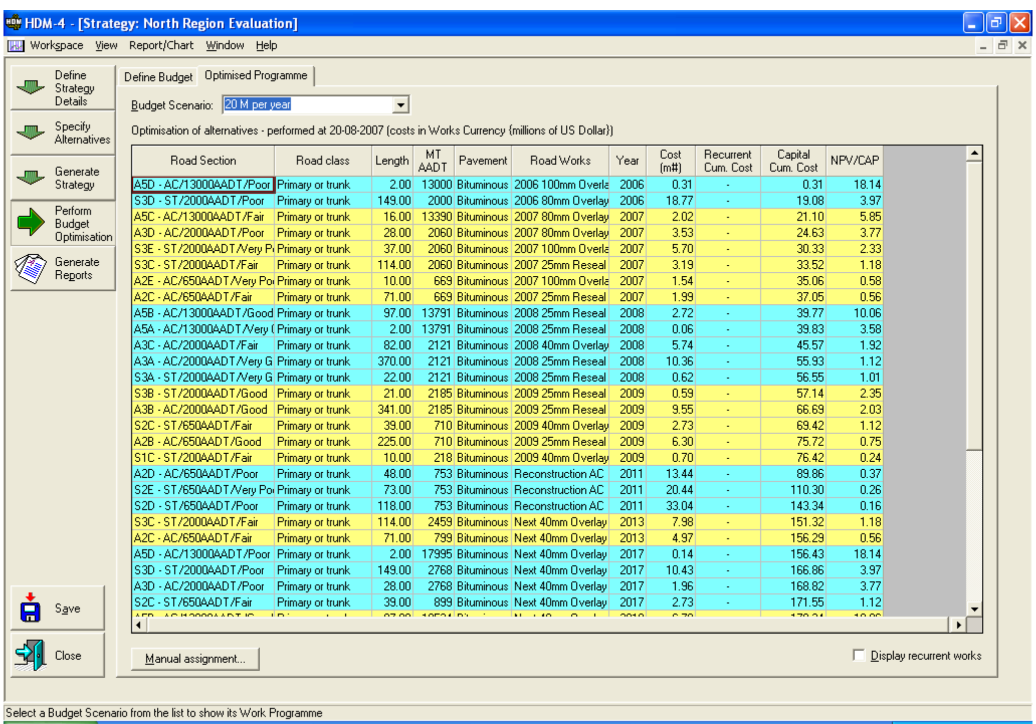


The screen below shows the optimization results for US$30 million per year, which show a more or less even distribution of expenditures from 2006 to 2009.



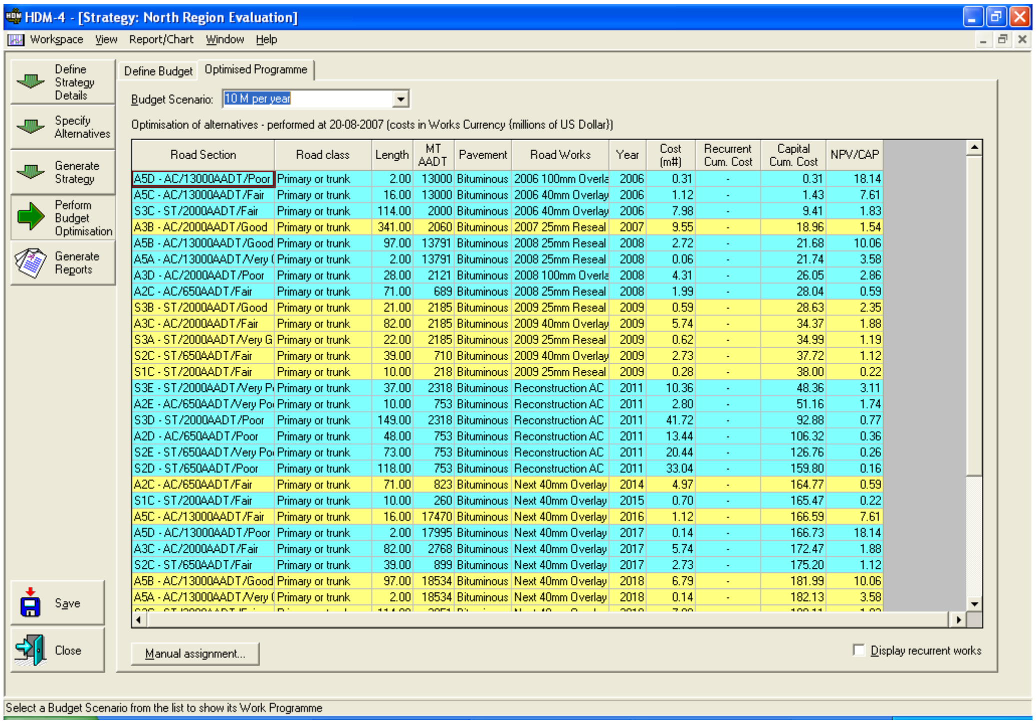
Road Section	Road class	Length	MT AADT	Pavement	Road Works	Year	Cost (m#)	Recurrent Cum. Cost	Capital Cum. Cost	NPV/CAP
A5D - AC/13000AADT/Poor	Primary or trunk	2.00	13000	Bituminous	2006 100mm Overla	2006	0.31	-	0.31	18.14
A5C - AC/13000AADT/Fair	Primary or trunk	16.00	13000	Bituminous	2006 40mm Overlay	2006	1.12	-	1.43	7.61
S3D - ST/2000AADT/Poor	Primary or trunk	149.00	2000	Bituminous	2006 80mm Overlay	2006	18.77	-	20.20	3.97
A3D - AC/2000AADT/Poor	Primary or trunk	28.00	2000	Bituminous	2006 80mm Overlay	2006	3.53	-	23.73	3.89
A3C - AC/2000AADT/Fair	Primary or trunk	82.00	2000	Bituminous	2006 40mm Overlay	2006	5.74	-	29.47	1.71
S3E - ST/2000AADT/Very P	Primary or trunk	37.00	2060	Bituminous	2007 100mm Overla	2007	5.70	-	35.17	2.33
S3C - ST/2000AADT/Fair	Primary or trunk	114.00	2060	Bituminous	2007 40mm Overlay	2007	7.98	-	43.15	1.95
S2C - ST/650AADT/Fair	Primary or trunk	39.00	669	Bituminous	2007 40mm Overlay	2007	2.73	-	45.88	1.04
S2E - ST/650AADT/Very Po	Primary or trunk	73.00	669	Bituminous	2007 100mm Overla	2007	11.24	-	57.12	0.65
A2E - AC/650AADT/Very Po	Primary or trunk	10.00	669	Bituminous	2007 100mm Overla	2007	1.54	-	58.66	0.58
A5B - AC/13000AADT/Good	Primary or trunk	97.00	13791	Bituminous	2008 25mm Reseal	2008	2.72	-	61.38	10.06
A5A - AC/13000AADT/Very (	Primary or trunk	2.00	13791	Bituminous	2008 25mm Reseal	2008	0.06	-	61.44	3.58
A2C - AC/650AADT/Fair	Primary or trunk	71.00	689	Bituminous	2008 40mm Overlay	2008	4.97	-	66.41	0.81
S2D - ST/650AADT/Poor	Primary or trunk	118.00	689	Bituminous	2008 80mm Overlay	2008	14.87	-	81.28	0.74
A2D - AC/650AADT/Poor	Primary or trunk	48.00	689	Bituminous	2008 80mm Overlay	2008	6.05	-	87.33	0.69
S3B - ST/2000AADT/Good	Primary or trunk	21.00	2185	Bituminous	2009 25mm Reseal	2009	0.59	-	87.92	2.35
A3B - AC/2000AADT/Good	Primary or trunk	341.00	2185	Bituminous	2009 25mm Reseal	2009	9.55	-	97.47	2.03
A3A - AC/2000AADT/Very G	Primary or trunk	370.00	2185	Bituminous	2009 25mm Reseal	2009	10.36	-	107.83	1.31
S3A - ST/2000AADT/Very G	Primary or trunk	22.00	2185	Bituminous	2009 25mm Reseal	2009	0.62	-	108.45	1.19
A2B - AC/650AADT/Good	Primary or trunk	225.00	710	Bituminous	2009 25mm Reseal	2009	6.30	-	114.75	0.75
S1C - ST/200AADT/Fair	Primary or trunk	10.00	218	Bituminous	2009 40mm Overlay	2009	0.70	-	115.45	0.24
A5C - AC/13000AADT/Fair	Primary or trunk	16.00	17470	Bituminous	Next 40mm Overlay	2016	1.12	-	116.57	7.61
A5D - AC/13000AADT/Poor	Primary or trunk	2.00	17995	Bituminous	Next 40mm Overlay	2017	0.14	-	116.71	18.14
S3D - ST/2000AADT/Poor	Primary or trunk	149.00	2768	Bituminous	Next 40mm Overlay	2017	10.43	-	127.14	3.97
A5B - AC/13000AADT/Good	Primary or trunk	97.00	18534	Bituminous	Next 40mm Overlay	2018	6.79	-	133.93	10.06
A3D - AC/2000AADT/Poor	Primary or trunk	28.00	2851	Bituminous	Next 40mm Overlay	2018	1.96	-	135.89	3.89
A5A - AC/13000AADT/Very (	Primary or trunk	2.00	18534	Bituminous	Next 40mm Overlay	2018	0.14	-	136.03	3.58

The screen below shows the optimization results for US$20 million per year.



Road Section	Road class	Length	MT AADT	Pavement	Road Works	Year	Cost (m#)	Recurrent Cum. Cost	Capital Cum. Cost	NPV/CAP
A5D - AC/13000AADT/Poor	Primary or trunk	2.00	13000	Bituminous	2006 100mm Overla	2006	0.31	-	0.31	18.14
S3D - ST/2000AADT/Poor	Primary or trunk	149.00	2000	Bituminous	2006 80mm Overlay	2006	18.77	-	19.08	3.97
A5C - AC/13000AADT/Fair	Primary or trunk	16.00	13390	Bituminous	2007 80mm Overlay	2007	2.02	-	21.10	5.85
A3D - AC/2000AADT/Poor	Primary or trunk	28.00	2060	Bituminous	2007 80mm Overlay	2007	3.53	-	24.63	3.77
S3E - ST/2000AADT/Very P	Primary or trunk	37.00	2060	Bituminous	2007 100mm Overla	2007	5.70	-	30.33	2.33
S3C - ST/2000AADT/Fair	Primary or trunk	114.00	2060	Bituminous	2007 25mm Reseal	2007	3.19	-	33.52	1.18
A2E - AC/650AADT/Very Po	Primary or trunk	10.00	669	Bituminous	2007 100mm Overla	2007	1.54	-	35.06	0.58
A2C - AC/650AADT/Fair	Primary or trunk	71.00	669	Bituminous	2007 25mm Reseal	2007	1.99	-	37.05	0.56
A5B - AC/13000AADT/Good	Primary or trunk	97.00	13791	Bituminous	2008 25mm Reseal	2008	2.72	-	39.77	10.06
A5A - AC/13000AADT/Very (	Primary or trunk	2.00	13791	Bituminous	2008 25mm Reseal	2008	0.06	-	39.83	3.58
A3C - AC/2000AADT/Fair	Primary or trunk	82.00	2121	Bituminous	2008 40mm Overlay	2008	5.74	-	45.57	1.92
A3A - AC/2000AADT/Very G	Primary or trunk	370.00	2121	Bituminous	2008 25mm Reseal	2008	10.36	-	55.93	1.12
S3A - ST/2000AADT/Very G	Primary or trunk	22.00	2121	Bituminous	2008 25mm Reseal	2008	0.62	-	56.55	1.01
S3B - ST/2000AADT/Good	Primary or trunk	21.00	2185	Bituminous	2009 25mm Reseal	2009	0.59	-	57.14	2.35
A3B - AC/2000AADT/Good	Primary or trunk	341.00	2185	Bituminous	2009 25mm Reseal	2009	9.55	-	66.69	2.03
S2C - ST/650AADT/Fair	Primary or trunk	39.00	710	Bituminous	2009 40mm Overlay	2009	2.73	-	69.42	1.12
A2B - AC/650AADT/Good	Primary or trunk	225.00	710	Bituminous	2009 25mm Reseal	2009	6.30	-	75.72	0.75
S1C - ST/200AADT/Fair	Primary or trunk	10.00	218	Bituminous	2009 40mm Overlay	2009	0.70	-	76.42	0.24
A2D - AC/650AADT/Poor	Primary or trunk	48.00	753	Bituminous	Reconstruction AC	2011	13.44	-	89.86	0.37
S2E - ST/650AADT/Very Po	Primary or trunk	73.00	753	Bituminous	Reconstruction AC	2011	20.44	-	110.30	0.26
S2D - ST/650AADT/Poor	Primary or trunk	118.00	753	Bituminous	Reconstruction AC	2011	33.04	-	143.34	0.16
S3C - ST/2000AADT/Fair	Primary or trunk	114.00	2459	Bituminous	Next 40mm Overlay	2013	7.98	-	151.32	1.18
A2C - AC/650AADT/Fair	Primary or trunk	71.00	799	Bituminous	Next 40mm Overlay	2013	4.97	-	156.29	0.56
A5D - AC/13000AADT/Poor	Primary or trunk	2.00	17995	Bituminous	Next 40mm Overlay	2017	0.14	-	156.43	18.14
S3D - ST/2000AADT/Poor	Primary or trunk	149.00	2768	Bituminous	Next 40mm Overlay	2017	10.43	-	166.86	3.97
A3D - AC/2000AADT/Poor	Primary or trunk	28.00	2768	Bituminous	Next 40mm Overlay	2017	1.96	-	168.82	3.77
S2C - ST/650AADT/Fair	Primary or trunk	39.00	899	Bituminous	Next 40mm Overlay	2017	2.73	-	171.55	1.12

The screen below shows the optimization results for US$10 million per year.

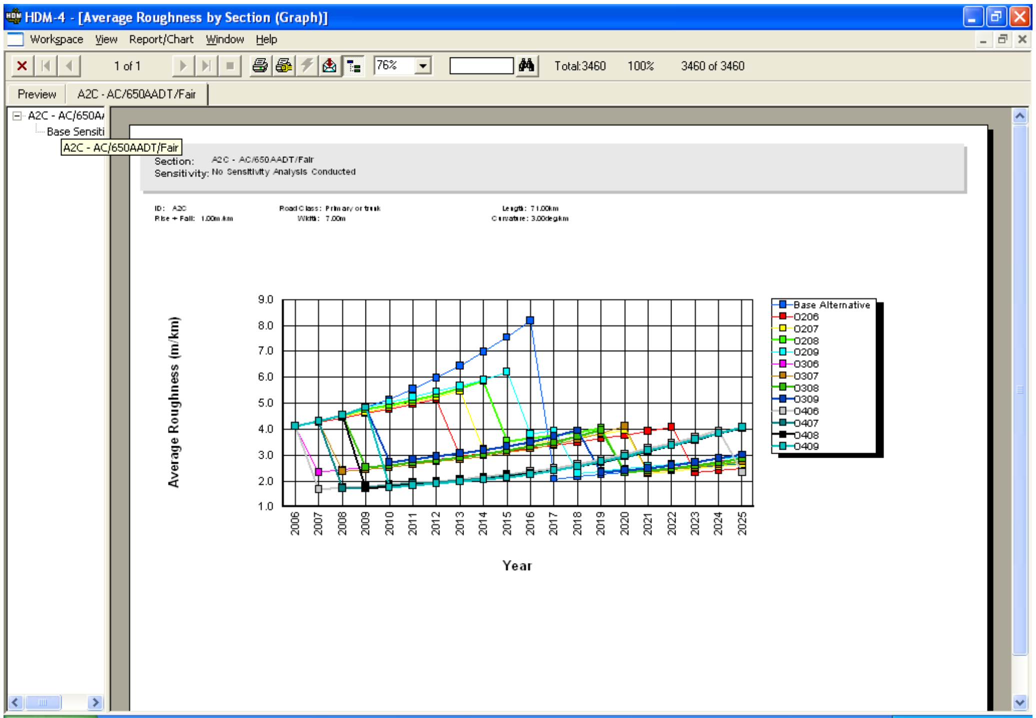


Road Section	Road class	Length	MT AADT	Pavement	Road Works	Year	Cost (m#)	Recurrent Cum. Cost	Capital Cum. Cost	NPV/CAP
A5D - AC/13000AADT/Poor	Primary or trunk	2.00	13000	Bituminous	2006 100mm Overla	2006	0.31	-	0.31	18.14
A5C - AC/13000AADT/Fair	Primary or trunk	16.00	13000	Bituminous	2006 40mm Overlay	2006	1.12	-	1.43	7.61
S3C - ST/2000AADT/Fair	Primary or trunk	114.00	2000	Bituminous	2006 40mm Overlay	2006	7.98	-	9.41	1.83
A3B - AC/2000AADT/Good	Primary or trunk	341.00	2060	Bituminous	2007 25mm Reseal	2007	9.55	-	18.96	1.54
A5B - AC/13000AADT/Good	Primary or trunk	97.00	13791	Bituminous	2008 25mm Reseal	2008	2.72	-	21.68	10.06
A5A - AC/13000AADT/Very (	Primary or trunk	2.00	13791	Bituminous	2008 25mm Reseal	2008	0.06	-	21.74	3.58
A3D - AC/2000AADT/Poor	Primary or trunk	28.00	2121	Bituminous	2008 100mm Overla	2008	4.31	-	26.05	2.86
A2C - AC/650AADT/Fair	Primary or trunk	71.00	689	Bituminous	2008 25mm Reseal	2008	1.99	-	28.04	0.59
S3B - ST/2000AADT/Good	Primary or trunk	21.00	2185	Bituminous	2009 25mm Reseal	2009	0.59	-	28.63	2.35
A3C - AC/2000AADT/Fair	Primary or trunk	82.00	2185	Bituminous	2009 40mm Overlay	2009	5.74	-	34.37	1.88
S3A - ST/2000AADT/Very G	Primary or trunk	22.00	2185	Bituminous	2009 25mm Reseal	2009	0.62	-	34.99	1.19
S2C - ST/650AADT/Fair	Primary or trunk	39.00	710	Bituminous	2009 40mm Overlay	2009	2.73	-	37.72	1.12
S1C - ST/200AADT/Fair	Primary or trunk	10.00	218	Bituminous	2009 25mm Reseal	2009	0.28	-	38.00	0.22
S3E - ST/2000AADT/Very P	Primary or trunk	37.00	2318	Bituminous	Reconstruction AC	2011	10.36	-	48.36	3.11
A2E - AC/650AADT/Very Po	Primary or trunk	10.00	753	Bituminous	Reconstruction AC	2011	2.80	-	51.16	1.74
S3D - ST/2000AADT/Poor	Primary or trunk	149.00	2318	Bituminous	Reconstruction AC	2011	41.72	-	92.88	0.77
A2D - AC/650AADT/Poor	Primary or trunk	48.00	753	Bituminous	Reconstruction AC	2011	13.44	-	106.32	0.36
S2E - ST/650AADT/Very Po	Primary or trunk	73.00	753	Bituminous	Reconstruction AC	2011	20.44	-	126.76	0.26
S2D - ST/650AADT/Poor	Primary or trunk	118.00	753	Bituminous	Reconstruction AC	2011	33.04	-	159.80	0.16
A2C - AC/650AADT/Fair	Primary or trunk	71.00	823	Bituminous	Next 40mm Overlay	2014	4.97	-	164.77	0.59
S1C - ST/200AADT/Fair	Primary or trunk	10.00	260	Bituminous	Next 40mm Overlay	2015	0.70	-	165.47	0.22
A5C - AC/13000AADT/Fair	Primary or trunk	16.00	17470	Bituminous	Next 40mm Overlay	2016	1.12	-	166.59	7.61
A5D - AC/13000AADT/Poor	Primary or trunk	2.00	17995	Bituminous	Next 40mm Overlay	2017	0.14	-	166.73	18.14
A3C - AC/2000AADT/Fair	Primary or trunk	82.00	2768	Bituminous	Next 40mm Overlay	2017	5.74	-	172.47	1.88
S2C - ST/650AADT/Fair	Primary or trunk	39.00	899	Bituminous	Next 40mm Overlay	2017	2.73	-	175.20	1.12
A5B - AC/13000AADT/Good	Primary or trunk	97.00	18534	Bituminous	Next 40mm Overlay	2018	6.79	-	181.99	10.06
A5A - AC/13000AADT/Very (	Primary or trunk	2.00	18534	Bituminous	Next 40mm Overlay	2018	0.14	-	182.13	3.58

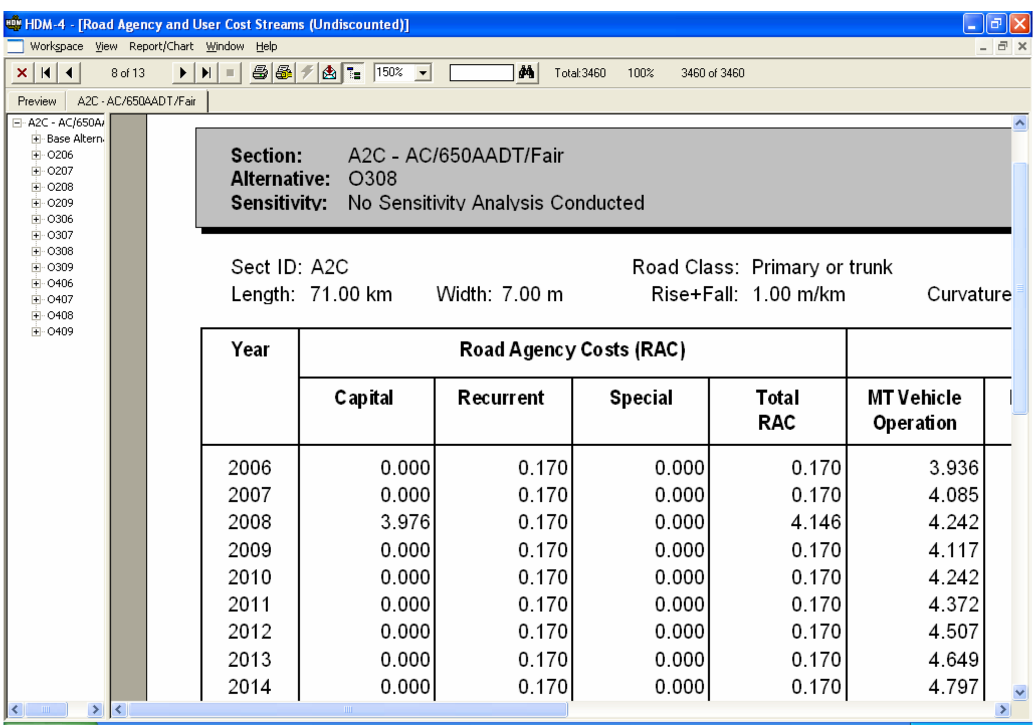
Generate Reports

All HDM-4 results are presented in a series of reports that were created to be printed on A4-sized paper. The reports should be viewed on the computer screen prior of performing the budget constraints optimization, to check if the HDM calculations are reasonable and to identify possible errors in the input data. When doing a strategic analysis, it is suggested that, at least, the following reports be reviewed: (i) Deterioration/Work Effects: *Average Roughness by Section*; (ii) Cost Streams and Economic Evaluation: *Road Agency and User Cost Streams (Undiscounted)*; and (iii) Cost Streams and Economic Evaluation: *Economic Indicators Summary*.

(i) *Deterioration/Work Effects: Average Roughness by Section (Graph).* Review the graphs to ensure that the road deterioration being modeled by HDM-4 is reasonable. For example, the screen below shows the deterioration for road class A2C, indicating that the timing of the road work is being modeled properly.

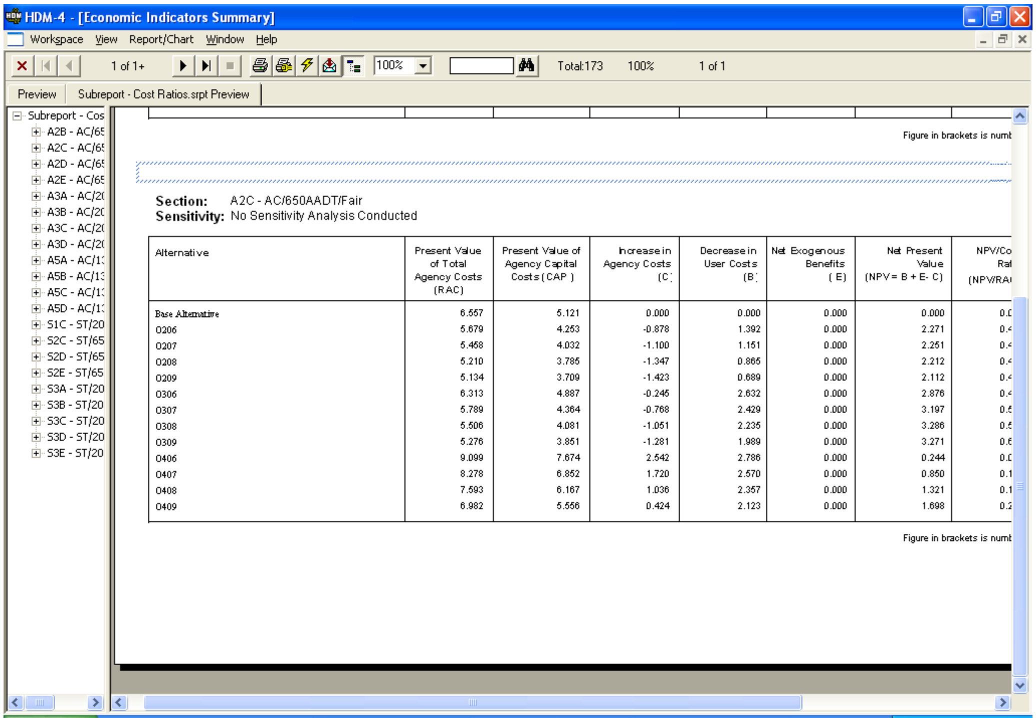


(ii) *Cost Streams and Economic Evaluation: Road Agency and User Cost Streams (Undiscounted).* Review the annual road agency costs to ensure that the unit costs of all road works were entered correctly and the definition of the maintenance standards is correct (timing of the road works). For example, the screen below shows the annual economic costs for road class A2C – project alternative O308. One can see that in 2008 road work O3 (40 mm Overlay) was executed with a capital economic cost of US$56,000/km, which is equivalent to US$8/m^2 for a 7 meter wide road.



Year	Road Agency Costs (RAC)				
	Capital	Recurrent	Special	Total RAC	MT Vehicle Operation
2006	0.000	0.170	0.000	0.170	3.936
2007	0.000	0.170	0.000	0.170	4.085
2008	3.976	0.170	0.000	4.146	4.242
2009	0.000	0.170	0.000	0.170	4.117
2010	0.000	0.170	0.000	0.170	4.242
2011	0.000	0.170	0.000	0.170	4.372
2012	0.000	0.170	0.000	0.170	4.507
2013	0.000	0.170	0.000	0.170	4.649
2014	0.000	0.170	0.000	0.170	4.797

(iii) *Cost Streams and Economic Evaluation: Economic Indicators Summary.* Review the economic comparison of project alternatives in terms of NPV. For example, the screen below shows the economic evaluation comparison for road class A2C, which shows that alternative O308 is the one with the highest NPV; therefore, it is the optimal alternative without budget constraints.



Alternative	Present Value of Total Agency Costs (RAC)	Present Value of Agency Capital Costs (CAP)	Increase in Agency Costs (C)	Decrease in User Costs (B)	Net Exogenous Benefits (E)	Net Present Value (NPV = B + E- C)	NPV/Co Rat (NPV/RA
Base Alternative	6.557	5.121	0.000	0.000	0.000	0.000	0.0
0206	5.679	4.253	-0.878	1.392	0.000	2.271	0.4
0207	5.458	4.032	-1.100	1.151	0.000	2.251	0.4
0208	5.210	3.785	-1.347	0.865	0.000	2.212	0.4
0209	5.134	3.709	-1.423	0.689	0.000	2.112	0.4
0306	6.313	4.887	-0.245	2.632	0.000	2.876	0.4
0307	5.789	4.364	-0.768	2.429	0.000	3.197	0.5
0308	5.506	4.081	-1.051	2.235	0.000	3.286	0.5
0309	5.276	3.851	-1.281	1.989	0.000	3.271	0.6
0406	9.099	7.674	2.542	2.786	0.000	0.244	0.0
0407	8.278	6.852	1.720	2.570	0.000	0.850	0.1
0408	7.593	6.167	1.036	2.357	0.000	1.321	0.1
0409	6.982	5.556	0.424	2.123	0.000	1.698	0.2

Exploring HDM-4 results

The HDM-4 model does *not* summarize the results of the comparison of budget scenarios automatically, by creating the tables and charts presented in this paper; therefore, it is necessary to manipulate the HDM-4 results in Excel, Access or another suitable software program to produce meaningful outputs. HDM-4 places all its output files in the Run Data Export Directory defined by the user. All the results of HDM-4 version 2.04 are saved in the Access file named “RunData.mdb”, which has many related tables. To be able to present all the tables and charts presented in this paper, the main tables and fields that need to be manipulated outside HDM-4 are given in the table below.

RunData.MDF main tables and fields			
Table	Main Fields	Description	Observations
HDM4RunData	DESC START_YEAR NUM_YEARS NUM_VEH NUM_SEC CURRENCY DISC_RATE	Strategy Description Calendar year of first year of evaluation period Number of years of analysis period Number of vehicles Number of road sections (road classes) Currency Discount Rate (%)	a) This table presents the basic run data
Vehicles	VEH_ID VEH_NAME	Vehicle ID Vehicle Name	a) This table presents all vehicle attributes b) The VEH_ID starts with 0 for the first vehicle c) Vehicles might not be sorted in a logical order
Sections	SEC_ID SECT_ID SECT_NAME LENGTH CWAY_WIDTH MT_AADT NM_AADT ROUGHNESS CRACKS_ACA CRACKS_ACT RAVEL_AREA PHOLE_NUM EDGEBREAK RUT_DEPTH LAST_SURF	Section ID Section code Section name Section length (km) Carriageway width (m) Motorized traffic (AADT) Non-Motorized traffic (AADT) Roughness (IRI) All structural cracks (%) Thermal cracks (%) Ravelled area (%) Number of potholes (#/km) Edge break area (m2/km) Rut depth (mm) Last surfacing year (year)	a) This table presents all section attributes b) The SEC_ID starts with 0 for the first section c) Sections might not be sorted in a logical order
SectOptions	SEC_ID OPT_ID	Section ID Option ID	a) This table shows the options (project alternatives) defined for each section b) Each option is given an OPT_ID that starts with 0 c) The OPT_ID increases continuously, it does not start with 0 for each section
Options	OPT_ID OPT_DESC SELECTED	Option ID Option Description Selected option without budget constraints (-1)	a) This table presents the description of each option (project alternative) b) The SELECTED flag is used to identify the option selected for each section without budget constraints (highest NPV)
SecOptData	SEC_ID OPT_ID NPV IRR	Section ID Option ID Net present value (currency) Internal rate of return (%)	a) This table presents the economic evaluation results of each option for each section (project alternative) without budget constraints
BudgetScenarios	BUDGET_ID	Budget scenario ID	a) This table presents the defined budget scenarios

	NAME DESC	Budget scenario name Budget scenario description	b) The BUDGET_ID starts with 0 for the first scenario
BudgetScenarios_ Options	BUDGET_ID SEC_ID OPT_ID	Budget scenario ID Section ID Option ID	a) This table presents the option selected for each section for each budget scenario
AnnualData	SEC_ID OPT_ID YEAR_INDEX LENGTH WIDTH MT_AADT NM_AADT IRIAV IRI_AW ACA_AW ACT_AW ARV_AW NPT_AW AEB_AW RDM_AW PTYPE_AW SNPK_AW THG_AW UNDBENF_22 UFIN_CAP UFIN_REC UFIN_SPEC	Section ID Option ID Year Length (km) Width (m) Motorized traffic (AADT) Non-Motorized traffic (ADT) Average roughness (IRI) After works roughness (IRI) After works structural cracks (%) After works thermal cracks (%) After works ravelled area (%) After works number of potholes (#/km) After works edge break area (m2/km) After works rut depth (mm) After works pavement type (code) After works adjusted structural number (#) After works gravel thickness (mm) Flow of net economic benefits (currency) Financial capital costs (currency) Financial recurrent costs (currency) Financial special costs (currency)	a) This table presents for each option (project alternative) and for each year the road condition and the economic evaluation results b) The YEAR_INDEX starts with 0 for the first year c) The average roughness is the average roughness during a calendar year d) The after works road condition indicators are measured at the end of the year, after maintenance work are executed e) The UNDBENF_22 contains the flow of net benefits that is used to compute the NPV and the IRR f) UFIN_CAP, UFIN_REC and UFIN_SPEC total the *financial* road agency costs g) UNDCOST_0, UNDCOST_1 and UNDCOST_2 total the *economic* road agency costs h) UNDCOST_6, UNDCOST_9, UNDCOST_12, UNDCOST_16 and UNDCOST_20 total the economic road user costs

	UNDCOST_0	Economic capital costs (currency)	
	UNDCOST_1	Economic recurrent costs (currency)	
	UNDCOST_2	Economic special costs (currency)	
	UNDCOST_6	Economic MT vehicle operating costs (currency)	
	UNDCOST_9	Economic MT travel time costs (currency)	
	UNDCOST_12	Economic NMT road user costs (currency)	
	UNDCOST_16	Economic accident costs (currency)	
	UNDCOST_20	Economic exogenous costs/benefits (currency)	

ANNEX B. ROAD COSTS KNOWLEDGE SYSTEM (ROCKS)

Road Works Classification for Preservation Works

Work Category	Work Class	Work Type	Predominant Work Activity
Preservation	Recurrent	Routine Maintenance	Routine Maintenance Earth Road Routine Maintenance Gravel Road Routine Maintenance Block 2L Highway Routine Maintenance Bituminous 2L Highway Routine Maintenance Concrete 2L Highway Routine Maintenance Bituminous > 2L Highway Routine Maintenance Concrete > 2L Highway Routine Maintenance Bituminous Expressway Routine Maintenance Concrete Expressway
	Periodic	Grading	Light Grading Heavy Grading
		Gravel Resurfacing	Regravelling
		Concrete Pavement Preventive Treatment	Concrete Pavement Preventive Treatment
		Bituminous Pavement Preventive Treatment	Fog Seal Rejuvenation
		Unsealed Preventive Treatment	Unsealed Preventive Treatment
		Surface Treatment Resurfacing	Slurry Seal or Cape Seal Single Surface Treatment Double Surface Treatment Triple Surface Treatment
		Asphalt Mix Resurfacing	Asphalt Overlay < 40 mm Asphalt Overlay 40 to 59 mm
	Rehabilitation	Strengthening	Asphalt Overlay 60 to 79 mm Asphalt Overlay 80 to 99 mm Asphalt Overlay > 99 mm Mill and Replace Mill and Replace 40 to 59 mm Mill and Replace 60 to 79 mm Mill and Replace 80 to 99 mm Mill and Replace > 99 mm Bonded Concrete Overlay Unbounded Concrete Overlay
		Concrete Pavement Restoration	Concrete Slab Replacement Concrete Slab Repair Concrete Diamond Grinding
		Reconstruction	Reconstruction Earth Reconstruction Gravel Reconstruction Block Reconstruction Bituminous Reconstruction Bituminous Surface Treatment Reconstruction Bituminous Asphalt Concrete Reconstruction Concrete

Number of Lanes
1L - One Lane   4L - Four Lane
2L - Two Lane   6L - Six Lane

Road Works Classification for Development Works

Work Category	Work Class	Work Type	Predominant Work Activity
Development	Improvement	Partial Widening	Partial Widening to Gravel 2L Partial Widening to Block 2L Partial Widening to Bituminous 2L Partial Widening to Concrete 2L
		Partial Widening and Reconstruction	Partial Widening and Reconstruction to Gravel 2L Partial Widening and Reconstruction to Block 2L Partial Widening and Reconstruction to Bituminous 2L Partial Widening and Reconstruction to Concrete 2L
		Widening	Widening Adding Bituminous 1L Widening Adding Bituminous 2L Widening Adding Bituminous 4L Widening Adding Concrete 1L Widening Adding Concrete 2L Widening Adding Concrete 4L
		Widening and Reconstruction	Widening and Reconstruction Adding Bituminous 1L Widening and Reconstruction Adding Bituminous 2L Widening and Reconstruction Adding Bituminous 4L Widening and Reconstruction Adding Concrete 1L Widening and Reconstruction Adding Concrete 2L Widening and Reconstruction Adding Concrete 4L
		Upgrading	Upgrading to Earth 2L Upgrading to Gravel 2L Upgrading to Block 2L Upgrading to Bituminous 2L Upgrading to Bituminous Surface Treatment 2L Upgrading to Bituminous Asphalt Concrete 2L Upgrading to Concrete 2L
	New Construction	New 1L Road	New Earth 1L Road New Gravel 1L Road New Block 1L Road New Bituminous 1L Road New Concrete 1L Road
		New 2L Highway	New Earth 2L Highway New Gravel 2L Highway New Block 2L Highway New Bituminous 2L Highway New Concrete 2L Highway
		New 4L Highway	New Bituminous 4L Highway New Concrete 4L Highway
		New 6L Highway	New Bituminous 6L Highway New Concrete 6L Highway
		New 4L Expressway	New Bituminous 4L Expressway New Concrete 4L Expressway
		New 6L Expressway	New Bituminous 6L Expressway New Concrete 6L Expressway

Number of Lanes

1L - One Lane 4L - Four Lane
2L - Two Lane 6L - Six Lane

ANNEX C. SUMMARY OF RECOMMENDATIONS

HDM-4 MODEL EVALUATIONS

- In a *project* economic evaluation, evaluate more than two project alternatives per project.
- In a *network* evaluation, use HDM-4 only to optimize *capital* road works, not *recurrent* road works.
- In a network evaluation, don't evaluate together paved roads and unpaved roads.

STRATEGIC PLANNING ROLE IN A ROAD AGENCY

- Present network monitoring indicators based on current road condition, without the need for HDM-4.
- Present the economic impact of budget constraints in terms of reduction of network NPV (efficiency frontier graph).
- Present budget constraints scenarios in a meaningful way (for example, 100 percent, 75 percent or 50 percent of the optimal expenditures).
- Present losses to society of budget constraints in relation to the optimal expenditures scenario.
- Present the Benefit-Cost Ratio of different budget constraints scenarios.
- Present the financial consequences of budget constraints for the road agency.
- Present the network in stable condition (good- and fair-condition roads) under different budget scenarios.
- Define the characteristics of roads in stable condition, based on country-specific data.
- Present a road condition forecast under different budget scenarios.
- Present the network utilization (million vehicle-km) per road condition category, as this is a better indicator than network length per road condition category.
- Present the average network roughness weighted by network length or network utilization.
- Complement the network roughness parameters' forecast with other road condition parameters' forecast (for example, area of cracking or total damaged area).
- Present the consequences of budget constraints for road users.
- Summarize the resulting work program and allocation of resources, for a given budget level, per network type, surface type, region, year, etc.
- Present a solution catalog showing, for a given budget level, the recommended types of road work and the timing of the road works.
- Present a solution catalog showing the recommended types of road work assuming the road works are executed now; present another catalog showing the recommended road works assuming the road works will be postponed by one year, and so on.

STRATEGIC PLANNING EVALUATION STEPS

- Collect all available road network data per homogeneous road section and assemble it into a road network database if needed.
- Collect network *aggregate* data if road network data is not available.
- Analyze the road network database or the road network aggregate data to establish a representative matrix of road classes.

- Define representative matrix cells' length and other attributes.
- Identify possible country-specific road works and estimate unit costs of road works in financial and economic terms.
- Define proper pragmatic project alternatives to be evaluated per matrix cell, considering the condition and traffic load of the roads and the current practices in the country.
- Establish country-specific road user costs.
- Define the planning period, evaluation period and discount rate.
- Enter input data into HDM-4 and run HDM-4.
- Evaluate different budget scenarios with HDM-4.
- Obtain from the HDM-4 output files, the raw results.
- Import the HDM-4 results into Excel and prepare output tables, charts and reports.
- Bring the results of the strategic planning study into the road network database, if available, for example, to produce maps of the results per road section.

ESTABLISHING A REPRESENTATIVE ROAD MATRIX

- Evaluate each homogeneous road section rather than a matrix of road classes, if the network length is relatively small (less than 3,000 to 4,000 km) and there is a network database with detailed information per homogeneous road section.
- Define the representative matrix at least as a function of surface type, roughness and traffic load.
- Complement, if possible, the characterization of road condition using roughness with cracking (surface distress) or deflections measures.
- Avoid defining the road condition categories using the "or" statement, for example, roughness less than 2.5 IRI, m/km, or cracking less that 5 percent.
- Include a road condition category that represents *zero cracking*, if cracking is adopted as a road condition criterion, because zero cracking indicates that the surface distress progression has not yet started.
- Avoid assigning a label to the road condition categories (Good, Fair, Poor, etc.), for example roughness, if only one road condition indicator is used to characterize the road condition.
- Adopt the same road condition categories (ranges of the road condition indicators) for asphalt concrete and surface treatment roads.
- Define several road classes but, if possible, limit the road classes to a total of 400, to be able to use the HDM-4 more precise EBM-32 optimization algorithm.
- Define the road classes in a way that broadly accords the same order of magnitude of number of kilometers to each road class.
- Adjust the traffic levels so as to distribute the number of kilometers more or less equally among the traffic levels.
- Define the road condition categories based on *technical* considerations, without attempting to distribute the number of kilometers per road condition category.
- Avoid having road classes with a very small number of kilometers (less than 5 to 10 kilometer); it is better to combine them into another cell.
- Convert network length to two-lane equivalent length if the number of lanes was not considered in the definition of the representative matrix.

DEFINING ROAD CLASS ATTRIBUTES

- Make an effort to quantify the key HDM-4 attributes of a road class—the length, width, pavement type, climate zone type, geometry type, traffic load and traffic composition, roughness, deflection or structural number, cracking, raveling, potholes, rut depth, pavement age and construction quality.
- Use engineering judgment to define the other road attributes.

DEFINING ROAD CLASS IDENTIFICATION CODES

- Assign a letter to the surface type.
- Assign a number to the traffic level.
- Assign one letter or two letters to the road condition category.

DEFINING ROAD WORKS

- Identify all possible types of road work that could be carried out on the network.
- Ensure that the country's standards support the identified road works.
- Estimate unit costs of the road work in *financial* and *economic* terms (net of taxes and subsidies).
- Assign a 2-character code to each road work, differentiating between *periodic maintenance* and *rehabilitation* works.
- Consider as a minimum three possible road works for bituminous roads: surface treatment resurfacing, asphalt concrete overlay and reconstruction.
- Explore as many different types of road work as possible, taking into account different materials, thicknesses and different shoulder works.
- Present the list of road works following the road works classification given in the Road Costs Knowledge System (ROCKS).
- Present a bar chart showing the unit costs per kilometer of road works to highlight that the rehabilitation costs are much higher than the periodic maintenance costs.

DEFINING PROJECT ALTERNATIVES

- Don't define purely condition-responsive or scheduled project alternatives.
- Define the project alternatives by scheduling the first capital road work needed per road class in different years, to be followed by a condition-responsive periodic maintenance standard that will keep the road in good to fair condition.
- Define first the existing types of road work in the country and then determine which road works to schedule per road class as a function of traffic load, condition and other road characteristics.
- Ensure that the selected road works are feasible from a technical point of view, yielding a reasonable design life.
- Define different project alternatives at least as a function of the road condition; traffic load could also be considered in a comprehensive analysis.
- Schedule the road works for roads in good condition not necessarily during the first years of the evaluation period.

- Refine the definition of the road work needed by changing the road works as a function of when they will be applied.
- Consider doing a preliminary analysis, evaluating all possible road work occurring in the first year of the evaluation period, to assist with the definition of road works to evaluate per road class.
- Define an appropriate condition-responsive periodic maintenance standard to be applied after the first capital road work, which should be a function of the traffic load of the road.
- Consider doing a separate study to identify the optimal condition- responsive periodic maintenance standards, as a function of the traffic load, in the country.
- Define a minimum reasonable time interval between the first capital road work and the next periodic maintenance road work.
- Define the recurrent maintenance works that will be done while the capital road works are postponed, for the cases of postponement of road works.
- Define, if possible, a maximum of 17 project alternatives, to remain within the limits of the HDM-4 more precise EBM-32 optimization algorithm.
- Define the "without project alternative" as the "do the minimum scenario" and not the "do nothing scenario".
- Include in the "without project alternative" a reconstruction when the road reaches poor condition (8 to 10 IRI, m/km), but ensure that no reconstruction is done during the first 6 to 12 years of the evaluation period, to avoid a reconstruction in the base case during the planning period.
- Define a project alternative that represents doing nothing or doing just routine maintenance, if needed, to show the consequences of zero available budget, but do not make this project alternative the "without project alternative".

DEFINING PROJECT ALTERNATIVES' NAMES

- Insert at the beginning of the project alternative's name the scheduled capital road work code (2 characters) followed by the timing of the scheduled road work (2 characters).

DEFINING VEHICLE FLEET CHARACTERISTICS AND ROAD USER COSTS

- Define the average vehicle fleet characteristics and estimate the economic vehicle fleet unit costs.
- Make an effort to quantify well the key HDM-4 attributes of a vehicle—new vehicle cost, kilometers driven per year, service life, maintenance labor cost, gross vehicle weight, fuel cost, new tire cost, number of passengers and passenger time cost.
- Present typical unit road user costs and the typical unit road user costs composition.
- Present the sensitivity of unit road user costs to roughness.

HDM-4 CALIBRATION

- Perform at least a Level 1 calibration of the mode.
- Refer to Volume 5 of the HDM-4 documentation for information on HDM-4 calibration and the sensitivity of the main input parameters.

Performing budget constraints optimization

- Define the planning period, defined as the initial three to six years of the evaluation period, depending on the country's budgeting process.
- Define a 20-year evaluation period, given that the evaluation period should be two to three times the planning period and that the maximum evaluation period of the EBM-32 optimization algorithm is 20 years.
- Ensure that the scheduled road works occur during the planning period and that the future condition-responsive maintenance works don't occur during the planning period.
- Ensure that the reconstructions of the "without project alternative scenario" don't occur during the planning period.
- Differentiate between the *theoretical* unconstrained budget scenario and a *practical* unconstrained budget scenario, in which the flow of expenditures is, broadly speaking, evenly distributed over the years.
- First find the theoretical unconstrained budget scenario and then perform a budget optimization, to find the practical unconstrained budget scenario that will require roughly the same total expenditures during the planning period.
- Evaluate other budget scenarios with lower expenditures *during the planning period*, but keep the expenditures *after* the planning period unconstrained.
- Represent the budget scenarios as a percentage of the expenditures under the *practical* "unconstrained budget scenario".

Support for programming of road works

- Support the decision-making process on programming of roads, if a network database of homogeneous road sections exists, by relating the results of the strategic evaluation, for a given budget level, to the homogeneous road sections.
- Relate the information by adding the road class code of each road section to each road section.
- Present for each road section the basic road characteristics, the recommended road work, the timing of the road work, the financial cost of performing the road work, the road section's NPV, and the NPV per investment cost ratio; sort the road sections by priority—sorting per year and per NPV per investment cost ratio.
- Present maps with the economic evaluation results per road section and other important considerations for decision-making, such as contract packaging and social considerations.

HDM-4 software

- Use classic style to define project alternatives.