METHODOLOGY FOR DETERMINING STRATEGIES FOR PAVEMENT PRESERVATION

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ABSTRACT
In recent years different schemes of financing for road preservation have begun to establish in Mexico and other nations, where a road or road network are granted as concessions to a company that provides the service during a specific period of time. The concessionaires must meet certain standards of performance throughout the life of the concession, such as IRI, rut depth, deflections, potholes, skid resistance, among others. Therefore, a methodology that allows determining in an initial way, preservation strategies throughout the concession period, carrying out the pavement management using the HDM-4 model is proposed. The methodology takes into account the type of road, traffic volume, vehicle classification, indicators such as IRI and rut depth, deflections, cracking levels, as well as the pavement age. The methodology uses mathematical models as well as pavement analysis results to determine the preservation strategies that will be studied in the HDM-4 model. This methodology may be used by the agencies responsible for conservation of roads, both network and individually.

1 PAVEMENT MANAGEMENT SYSTEMS

The pavement administration systems have been defined by "AASHTO" as a set of tools or methods that help in the decision making process to find optimal strategies for the purpose of providing, assessing and maintaining pavements in a condition of service in a period of time. [1]
The activities of the pavement management are focused on two distinct levels: network and project level. [2] The network level is the overall view of the pavement infrastructure and aims to matters of planning and general budget. The project level has a local focus on a limited part of the network. This is the level where specific decisions about maintenance strategies and allocation of funds are made.

1.1. Network-level activities

The purpose and goals of the management process at the network level are related to the budgeting process and include:
1. Identification of the maintenance, rehabilitation and reconstruction needs of the pavement.
2. Determination of the necessary funds for the care of those needs.
3. Feasibility analysis of financing alternatives and strategies to be applied.
4. Determination of the impact of financing alternatives in pavement performance as well as the impact on the users' safety.
5. Development of optimal budget recommendations.

In general, pavement administration systems assist in the planning stages, programming, budgeting and analysis. Analysis at network level involves identifying maintenance needs, funding needs, the impact of different financing alternatives considered, and priority-setting project. These results can be used in general to provide administrative, legal and technical support in defining the actions to follow.

1.2. Project level activities

The pavement management system at the network level consists of different activities at project level. At this level, the purpose of a pavement management system is to provide the greatest benefit/cost as well as the most optimal possible strategy of design, maintenance, rehabilitation or reconstruction for a selected pavement section within available budgets and other restrictions. In general, it must include the following:

1. An assessment of the need to build or cause of distress.
2. Identification of feasible strategies for maintenance, rehabilitation and reconstruction.
3. Cost/benefit analysis of different alternatives.
4. Defining imposed restrictions.
5. Selecting the greatest benefit / cost strategy, considering the restrictions imposed.

This stage is often referred to as preliminary design because it does not include pavement designs, plans or specifications.

1.3. Network-level elements

The basic elements of a pavement management system at the network level include an inventory, an evaluation of its condition, determination of needs, prioritization of projects that require maintenance and rehabilitation, a method for determining the impact of financing decisions and a feedback process. This global system is composed by two major subsystems. Information management system collects stores and manages the data. Decision support system is the set of algorithms that analyzes data and provides recommendations to managers. Thus, network-level elements include:

1. Defining the limits of the network.
2. Developing an inventory of roads within the network.
3. Developing a condition survey which identifies different pavement distresses.
4. Developing maintenance strategies, cost estimates and expected life.
5. Determining rehabilitation or reconstruction needs.
6. Analyzing costs of rehabilitation and reconstruction.
7. Determining overall needs of the network.
8. Prioritizing rehabilitation and reconstruction needs considering the limitations of funds.
9. Forecasting the future condition of the network and the impact of funding.

10. Implementing a feedback system to update costs, life expectancies, revise rehabilitation and reconstruction strategies, as well as improve the reliability of the system.

1.3.1 *Inventory*

The network level inventory is the database of basic information. It generally includes information that defines the type of sections of pavement, location, limits, key number, geometry (length, width, number of lanes), route designations, jurisdiction (federal, local, municipal, etc.), functional classification, historical information (construction dates, the last treatment), pavement characteristics (flexible, rigid, mixed). This information is provided only once in the database. Only if major changes occur, like an expansion of lanes or change of pavement type, this database is changed.

1.3.2 *Pavement condition assessment*

Pavement condition assessment includes activities related to data collection to determine the type, amount and severity of surface damage, structural capacity, roughness and skid resistance of the pavement. This information will help to define the requirements for maintenance, rehabilitation or reconstruction, to foresee future status of the project and identify the impacts of treatment. Similarly, it serves to identify feasible strategies for rehabilitation and reconstruction to prioritize and optimize costs. Pavement condition is normally measured using the following factors:

1.3.2.1 Surface distress

Information should contain the type, severity and quantity of surface deteriorations. This determines the Pavement Condition Index (PCI). Surface distress and PCI are used to identify the time of maintenance and rehabilitation, as well as the fund needs in the pavement management process. Among the different types of impairments can be differentiated which are caused by functional mechanisms, such as transverse cracking by reflection, or those directly related to impairment charges, such as rutting or cracking in crocodile skin form, and those caused by weather conditions or characteristics of the materials. The PCI suggests the primary mechanisms causing the deterioration. [3]

1.3.2.2 Structural capacity

The analysis focuses on determining the capacity of existing load that can be compared with the required capacity to handle traffic on the analysis horizon. For this process nondestructive testing of deflections are recommended.

1.3.2.3 Surface roughness

Surface roughness of pavement can turn into an index of service (IS) or in the international roughness index (IRI). Pavement roughness is the most important indicator of pavement condition related to the user, especially when it comes to high-speed tracks (above 70 km/h), which is directly related to vehicle operating costs (VOC).

1.3.2.4 Surface Friction

Skid resistance is the ability of an asphalt surface to minimize sliding of the vehicle tires, especially when the road surface is wet. It is measured in terms of a number or coefficient of friction. This is an important value when vehicles operate at high speeds. The measurement is independent of the condition of surface pavement and can be used to determine the need for surface treatments to improve road safety.

1.3.2.5 Determination of needs

After the network is defined and the data collection is made, it is necessary to know the type of works and resources required for this in an analysis period defined for a given service level associated with user fees.

1.3.2.6 Ranking

Once the pavement sections that require maintenance, rehabilitation or reconstruction, and the necessary funds to provide the desired service level are identified, it is necessary to rank and determine priorities. In most cases the available resources are less than needed. Even when resources are available, these generally should be spread among a number of years and should match jobs with available resources. The goal of ranking is to provide greater benefits to the users for the distributed funds; in this way, those roads with the highest traffic often have higher priority than those with lower traffic.

1.3.2.7 Determining the impact of funding decisions

The overall goal of government agencies is to provide the maximum social benefit for the money provided by the users, either by taxes or by toll collection. One of the main problems that the pavement infrastructure has faced, is that those responsible for it have not had long-term vision and are more interested in immediate impact results, even though these benefits result in short term. Long-term solutions are rarely easily understood by managers of road networks, so it is necessary that the engineers who are dedicated to managing pavements to have the necessary elements to justify long-term projects; i.e., 15, 20, 25 or even more years. In Mexico and many emerging nations, even in developed countries, the officials who make decisions to allocate funds to execute the works that require a road network, often choose to solve immediate problems, sometimes "emergency techniques", same which would have not occurred, if they had been taken into account in a long-term plan.

1.3.2.8 Feedback process

Whenever a system is implemented, such as the pavement management, a feedback process is needed to provide information and previous estimates are compared with values observed in a way that may improve the future estimates.

1.4. Elements at project level

The pavement management at this level is a process of analysis and design to determine the type of materials and thicknesses of the layers necessary for the pavement structure. Pavement management activities at project level usually include new rehabilitation or reconstruction designs, as well as the maintenance program required to maintain the level of desired service.

1.4.1. Design

A rational design process must consider the main factors affecting pavement performance. Every pavement design is based on the factors affecting the pavement and includes:

1. The resistance of the ground support
2. Expected traffic loads
3. Environmental factors
4. Drainage
5. Available materials
6. Capacities of building techniques
7. Costs

1.4.2. Development of projects and maintenance, rehabilitation, and reconstruction programs.

Just like the activities of an initial pavement construction, those for rehabilitation and reconstruction activities are also expensive. The design of the maintenance, rehabilitation and building can take more time, effort and funds than the design of a new pavement because the properties of existing materials should be considered as one of the various alternatives to address the existing problems. Once the default behavior that needs to be corrected is identified, as well as its causes; it is necessary to identify the potential treatments that can correct and analyze its feasibility. For the definition of conservation strategies is also necessary to consider, among other things, the following: the proper structuring of the pavement for future transit on the horizon of the project, deterioration rate, types of existing materials, type of drainage, maintenance records, condition of pavement along the length and between lanes, environmental factors that require special consideration, traffic control, geometric factors that impact in the behavior, and so on.

One of the many difficulties to be faced is the amount and extent of data to be gathered because it also depends on the resources allocated to evaluation activities and data collection, as well as definitions that had been made for it. Not necessarily the greater information available the better results. E.g., in terms of structural capacity, it can be decided to make deflections to the pavement in each lane on a track of 100 km four-lane. If the deflections are made every 500 m, it will be 800 data in total, but if it is decided to make measurements every 5 m in total will be 80,000 data; hence, it should be defined in advance the type, amount and extent of measurements to be made because at first the data storage mechanism can be very robust, but at the moment of processing information, not necessarily all information must be used, nor be detailed because it could hinder its operation.

Something similar goes for any other type of information, e.g., photographs or video of right of way; the greater the information available, it requires greater and more efficient hardware and software resources for management. Derived from the above, it is necessary to define priorities from these stages according to the type of roads subject to pavement management system, e.g., roads with higher traffic volumes may require more quantity of information that roads with low traffic volume. There is a great variety of alternatives for maintenance, rehabilitation and reconstruction for different types of pavement: flexible, rigid or mixed; where pavement recycling activities have been handled as one of these alternatives within the last years. As preventive maintenance treatments, superficial treatments may be mentioned; such as seal, micro layers of different types and thicknesses, which are also sometimes used as rehabilitation strategies in low-traffic routes where no action is required on increasing the structural capacity of pavement. It can also be mentioned the double layers, or shaped layers and placing a new layer, or combinations of inter-layers on a recycled layer. Recycled and reused materials can be stabilized with a stabilizing agent that can be any asphalt binder, Portland cement or sometimes lime. In general, for flexible pavements the following types of rehabilitation and reconstruction can be mentioned: Cold recycling in the place with a new superficial layer, hot recycling with or without up layer, recovery and stabilization of lower layers as sub-basis or basis, followed by a new superficial layer removal and partial or full replacement of the different layers, total depth recycling white topping (on hydraulic concrete layer). For rigid pavements include: replacement of slabs, partial or total depth, surface pitting, joint sealing, asphalt overlay, broken slabs of concrete and overlay of hydraulic concrete or asphalt, etc.

1.4.3. Selecting the most appropriate maintenance strategy

The process for selecting a combination of treatments, materials and thicknesses for the new design, maintenance, rehabilitation or reconstruction is an important step in the process of project design. The approach pursued in the analysis at project-level should include a preliminary pavement design using available materials and treatments considered as feasible under established circumstances, so, the right combination must be required in order to provide the lowest costs in the project life cycle; it is also necessary to determine the cost of each one of the conservation strategies, and taking into account the maintenance and rehabilitation actions as well as their impact on operating costs from users.

1.5. Life cycle cost analysis

To assess the total economic cost of the project it is necessary to follow a process of analysis that considers the initial costs and discounted future costs, such as maintenance costs, users, reconstruction, rehabilitation and repaving during the project's horizon. This analysis technique helps to make the best decisions in terms of investment taking into account criteria for economic analysis of the variety of alternatives, designs and strategies.

In this process the following aspects and analysis criteria should take into account.

1.5.1. Pavement design

It is a project-level activity where detailed engineering and economic considerations should be given to alternate combinations of sub-base, base and surface materials to provide the required load capacity. Factors to be considered include materials, traffic, weather, maintenance, drainage, and life cycle costs.

1.5.2. User costs

User costs are costs incurred by users who travel along the route in question and the excess of costs incurred by those who do not use the route in question because of any requirement imposed by the operating agency. User costs are the sum of three components: vehicle operating costs (VOC), crash costs and user delay costs.

1.5.3. Benefit/cost Analysis (B/C)

The B/T analysis represents the discounted benefits of an alternative divided by net discounted cost. If the B/C relation is greater than 1.0, it means that the benefits exceed the costs.

1.5.4. Internal rate of return (IRR)

The IRR represents the discounted rate required for the net present value to be equal to zero, i.e., the discounted costs match discounted benefits. This indicator is very useful especially when it comes to budgets with restrictions or when there is uncertainty about the appropriate discount rate.

1.5.5. Net present value (NPV)

NPV is the discounted monetary value of expected net benefits. The methodology consists of discounting to current moment all future cash flows of the project. The initial investment is subtracted from this value, so the result is the net present value of the project.

1.5.6. Alternative strategies

The main purpose of the life cycle is to quantify which would mean short and long terms, to apply any of the alternative conservation strategies. A pavement design strategy is the combination of initial pavement design with the necessary maintenance and rehabilitation activities.

2. DESCRIPTION OF THE HDM-4 MODEL

The HDM-4 is a set of tools for technical and economic analysis of investment alternatives related to the conservation and improvement of roads, these tools are integrated into a computer program developed by the University of Birmingham, as the main product of International Study of Highway Development and Management

(ISOHDM).
The tools incorporated into the HDM-4 allow tasks such as: predicting the deterioration of the pavement during its life, calculate the effects of conservation activities and improvement of pavement, estimate vehicle operating costs and other costs of road infrastructure users, determine the effects of congestion on the vehicle motion speed in vehicle operating costs. To evaluate projects, policies and conservation programs in technical and economic terms, getting the costs and benefits of each alternative considered and to calculate the profitability indicators like Net Present Value (NPV) and Internal Rate of Return (IRR). In general terms, costs included in the analysis correspond to current expenditure and investment in which the operating organization must incur to run the works, while the benefits are derived primarily from savings in vehicle operating costs and reductions in travel time, induced both by improving the physical condition of the roads and reducing congestion. Optimize conservation and improvement programs subject to financial constraints. Either calculate the amount of investment required to maintain a certain level of service in a network of roads, or estimate the level of service that can be achieved with a given budget. Assess the effects of long-term policies such as changes in legal charges of traffic, pavement preservation standards and design standards.
Among the components illustrated in figure 1, that relating to the internal models of the system, stands out. The HDM-4 uses three groups of models:
1. Road Deterioration and Works Effects (RDWE). These models allow to predict, for a period of analysis defined by the user, the evolution of the physical state of the roads, according to the requests imposed by traffic, the weather conditions and the type of pavement; likewise, the models estimate the effects of most common maintenance and improvement works.
2. Road User Effects (RUE) are used by the system to calculate the effects of the physical state and operating conditions of the roads on the users of the same, in terms of indicators such as vehicle operating costs and travel times. At the same time, these indicators are used to obtain investment’s benefits in highway projects.
3. Safety, Energy and Environmental Effects (SEE), group of models for determining the effects of the condition of pavements in areas such as accident rate, the energy consumption associated with operation of traffic and use of construction equipment, and pollutant emissions.
Another major component of HDM-4 is composed of analysis tools and system applications, which have the purpose of evaluating projects, programs and strategies for conservation and improvement of roads and program optimization in the presence of budget restrictions, as described below:

1. Project analysis. It refers to the evaluation of project alternatives for the conservation and improvement of a set of tracks, for a given analysis period. The system compares the alternatives using economic profitability indicators, which derived from the annual costs and benefits of each alternative.
2. Program analysis. Consists basically in the hierarchy of a list of candidate projects according to their profitability level, in order to obtain a program of yearly or multi-annual work that meets the budget constraints of the organization during

the period considered. The analysis of programs allows getting a combination of project alternatives that maximize economic return of the investments, taking into account existing resource constraints.

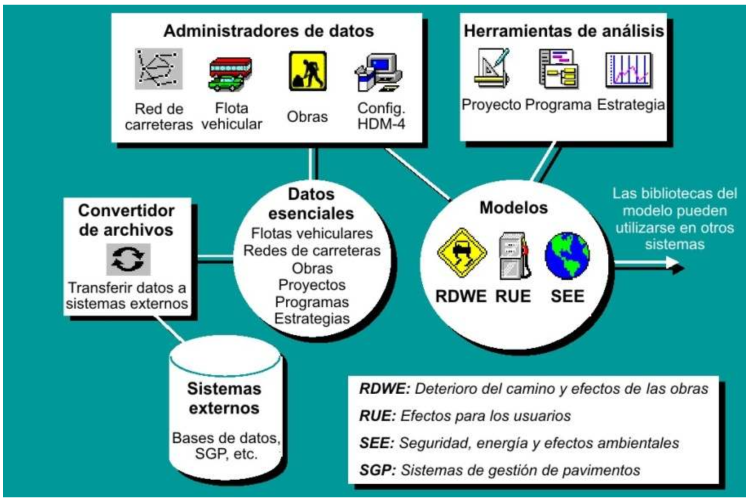

Figure 1 - Architecture of the HDM-4 System [4]

3. Analysis of strategies. Its purpose is to evaluate long-term policies for the conservation and improvement of a network or subnet of roads. Among the specific problems that can be solved with this type of analysis we find the calculation of the amount of investment required to achieve certain level of service on the network, determining the future status of the network for current levels of investment and evaluation of conservation standards, among others.

The HDM-4 covers the components, of these systems, relating to the analysis tools, i.e., models and procedures for predicting pavement deterioration, the evaluation of policies, and conservation and improvement projects, formulation and optimization of work programs, and evaluating the impact of different strategies for highway development in the network behavior.

Therefore, the HDM-4 provides the necessary components for the implementation of pavement management systems, so it can be considered a useful product.

3. METHODOLOGY TO DETERMINE CONSERVATION STRATEGIES

The use of the HDM-4 model, even though it is an automated process, requires having extensive knowledge of the issues of structural and functional evaluation of pavements, load requests and preservation strategies, among other things. So that to carry out pavement management tasks, a staff trained and dedicated exclusively to such tasks is required.

In order to assist in the process, after obtaining the necessary information from the network analysis, a simplified methodology is proposed that on the one hand allows us to identify priorities over the network segments that require to be located as priority attention, and on the other hand, it will help in the determination of conservation strategies that will run on the HDM-4 model, so that the allocation of resources for conservation of pavement can be optimized, identifying those projects where the conservation plan offers higher profitability.

The methodology is focused on roads or highways that meet the following: variable AADT; however, the methodology aims to separate and group the conservation strategies at different levels of heavy traffic, only to define the strategy to be followed; nonetheless, in the analysis and modeling with the HDM-4, the AADT with its vehicle classification, and rates of growth on the horizon of the project are taken into account, a methodology that applies only to flexible pavements.

3.1. Selection of the variables of analysis

The basic definitions of the used variables are:

3.1.1. Traffic

The traffic defines the loads to which the pavement will be subjected during its life cycle, and is related to the required standard. In order to characterize the network, traffic is separated into four levels of charge, according to the volume of heavy vehicles; this is the type B and C. These levels are: 1. Low traffic (below 450 heavy vehicles per day), 2. Medium (from 450 to 1,500 vehicles heavy per day), 3. high (from 1,500 to 3,400 of heavy vehicles per day) and 4. Very High (more than 3,400 heavy vehicles per day).

3.1.2. Structural Condition

The structural variable defines the support of the pavement condition at the time of evaluation, which will estimate the necessary structural support that pavement must have on the basis of the requests during the period of analysis. This variable is defined by the recorded deflections. In case these measures are not fulfilled, the use of other variables such as rut depth in conjunction with the crocodile skin cracking, never the less it is recommendable to realize the uplifting of deflection in the pavement to give more certainty to the analysis. The deflections registers can also be separated in different ranges; Low for minor 0.25 mm deflections, medium from 0.25 to 0.41mm and High for more than 0.41 mm deflections.

3.1.3. Functional condition

The functional variable defines the level of service of the pavement at the moment of the evaluation and it is represented by the IRI, because it is directly related with the user's comfort and the operation costs when using the road. To represent the condition of the pavement and the type of road, it is proposed to put into three groups of IRI levels, Good if it is minor to 3, Regular from 3 to 5 and Bad if it is above 5.

3.1.4. General condition

The variable associated to the general condition of the pavement is defined by the age of the pavement; this is also directly related to the presence of structural and functional failures such as cracking and pot holes. The age variable is not evaluated, for this reason it is necessary to find historical background in relation to this value. It is proposed to divide into three ranges, minor ages for less than 7 years, from 7 to 15 years and mayor for more than 15 years.

3.2. Pavements Scenarios Matrix

According to the above considerations, the development of a scenarios' matrix that considers the formulated variables, with the values found in the assessment is proposed. Thus it is possible to formulate the following matrix:

CRITERIO PARA DEFINIR ESTRATEGIA DE CONSERVACION INICIAL													
Veh pesados diarios		<450			450 - 1,500			1,500 - 3,400			> 3,400		
Deflexión		Baja < 0.25	Media 0.25 - 0.40	Alta > 0.40	Baja < 0.26	Media 0.25 - 0.41	Alta > 0.41	Baja < 0.27	Media 0.25 - 0.42	Alta > 0.42	Baja < 0.28	Media 0.25 - 0.43	Alta > 0.43
IRI Existente	Edad Pavimento												
< 3	< 7												
	7 - 15												
	> 15												
3 - 5	< 7												
	7 - 15												
	> 15												
> 5	< 7												
	7 - 15												
	> 15												

Figure 2 – Matrix for defining conservation strategy

3.3. Proposal of preservation strategies for conservation, rehabilitation and reconstruction

In this stage the strategies of conservation, rehabilitation or reconstruction technically possible to apply for each type of pavement, and for each scenario defined, are proposed.

The preservation strategies must be carefully selected, taking into consideration that as it was established in the first chapter, a feedback process that would allow the modification of the strategies must exist. However, a first proposal is made taking as a base the preliminary pavement designs, as alternatives of initial conservation indicated in the figure 3.

CLAVE	ACTIVIDAD		ALCANCE
0	Conservación rutinaria		A realizar todos los años, incluye deshiebe, desazolve de obras de drenaje, cunetas, bacheo superficial <5%, señalamiento horizontal, etc.
1	Bacheo Superficial en 5 % de la superficie		Considera realizar el bacheo en 5% del total de la superficie de rodamiento indicada.
2	Riego de sello		Riego de sello premezclado empleando emulsion asfaltica y material 3-A
3	Bacheo Profundo en 10 % superficie+Riego de sello		Bacheo profundo, con riego de sello empleando emulsion asfaltica con material 3-A
4	Microcarpeta		De 3.5 cm de espesor tipo SMA
5	Sobrecarpeta de 5 cm		Carpeta asfáltica densa
6	Sobrecarpeta de 8 cm		Carpeta asfáltica densa
7	Perfilado y carpeta de 10 cm		El espesor del fresado es de 10cm y el material resultante se considera como desperdicio, carpeta asfaltica densa de 10 cm.
8	Recuperación de BEC + carpeta de 5 cm		Recuperación de los materiales existentes de carpeta y base, estabilizando con cemento portland y colocación de carpeta densa de 8 cm de espesor.
9	Recuperación de BEC + carpeta de 10 cm		Recuperación de los materiales existentes de carpeta y base, estabilizando con cemento portland y colocación de carpeta densa de 10 cm de espesor.

Figure 3 - Initial proposal for preservation strategies

Once the proposal of initial conservation actions is proposed, it follows a mathematical procedure to define in the matrix, each of the conservation strategies, for which an analysis variables is made, as follows:

Criterio	Incidencia	Niveles Valor	Calificacion /Nivel	Calificacion Max	Calificacion Min	Procedim-Inicio	Rango Menor	Rango Mayor
IRI	45.00%	3	3.3333	4.5000	1.5000	0	3.0833	6.0000
TDPA	30.00%	4	2.5000	3.0000	0.7500	1	6.0001	6.4444
Edad Pav	15.00%	3	3.3333	1.5000	0.5000	2	6.4445	6.8889
Deflexión	10.00%	3	3.3333	1.0000	0.3333	3	6.8890	7.3333
Total	100.00%			10.0000	3.0833	4	7.3334	7.7778
				Dif Calif Max-May	4.0000	5	7.7779	8.2222
				Rango por Nivel Calif	0.4444	6	8.2223	8.6667
						7	8.6668	9.1111
						8	9.1112	9.5556
						9	9.5557	10.0000

Figure 4 – Variables of analysis

In this case, in the analysis, an incidence of 45% was assigned to the variable IRI, 30 % to the transit, 15% to the age, and 10% to deflections. Subsequently, maximum and minimum scores will be obtained, as well as minor and mayor ranges, which will be related to the strategies' keys previously defined. Once the mathematical processes are done, the following values are obtained:

Calculo de Valores													
Veh pesados diarios		<450			450 - 1,500			1,500 - 3,400			> 3,400		
Deflexión		Baja	Media	Alta	Baja	Media	Alta	Baja	Media	Alta	Baja	Media	Alta
IRI Existente	Edad Pavimento												
< 3	< 7	3.0833	3.4167	3.7500	3.8333	4.1667	4.5000	4.5833	4.9167	5.2500	5.3333	5.6667	6.0000
	7 - 15	3.5833	3.9167	4.2500	4.3333	4.6667	5.0000	5.0833	5.4167	5.7500	5.8333	6.1667	6.5000
	> 15	4.0833	4.4167	4.7500	4.8333	5.1667	5.5000	5.5833	5.9167	6.2500	6.3333	6.6667	7.0000
3 - 5	< 7	4.5833	4.9167	5.2500	5.3333	5.6667	6.0000	6.0833	6.4167	6.7500	6.8333	7.1667	7.5000
	7 - 15	5.0833	5.4167	5.7500	5.8333	6.1667	6.5000	6.5833	6.9167	7.2500	7.3333	7.6667	8.0000
	> 15	5.5833	5.9167	6.2500	6.3333	6.6667	7.0000	7.0833	7.4167	7.7500	7.8333	8.1667	8.5000
> 5	< 7	6.0833	6.4167	6.7500	6.8333	7.1667	7.5000	7.5833	7.9167	8.2500	8.3333	8.6667	9.0000
	7 - 15	6.5833	6.9167	7.2500	7.3333	7.6667	8.0000	8.0833	8.4167	8.7500	8.8333	9.1667	9.5000
	> 15	7.0833	7.4167	7.7500	7.8333	8.1667	8.5000	8.5833	8.9167	9.2500	9.3333	9.6667	10.0000

Figure 5 - Calculation of values to define strategies

The next step is to obtain a matrix that defines the initial preservation strategies, as shown in Figure 6.

Determinacion del criterio de estrategia de conservación inicial													
Veh pesados diarios		<450			450 - 1,500			1,500 - 3,400			> 3,400		
Deflexión		Baja	Media	Alta	Baja	Media	Alta	Baja	Media	Alta	Baja	Media	Alta
IRI Existente	Edad Pavimento												
< 3	< 7	0	0	0	0	0	0	0	0	0	0	0	0
	7 - 15	0	0	0	0	0	0	0	0	0	0	1	2
	> 15	0	0	0	0	0	0	0	0	1	1	2	3
3 - 5	< 7	2	2	2	2	2	2	2	2	2	2	3	4
	7 - 15	2	2	2	2	2	2	2	3	3	3	4	5
	> 15	2	2	2	2	2	3	3	4	4	5	5	6
> 5	< 7	2	2	2	2	3	4	4	5	6	6	6	7
	7 - 15	2	3	3	3	4	5	5	6	7	7	8	8
	> 15	3	4	4	5	5	6	6	7	8	8	9	9

Figure 6 - Determination of initial conservation strategies

The matrix above shows the keys defined for conservation strategies depending on the conditions and characteristics of network analysis. It is noteworthy that this methodology is simply a help sheet to define how the initial conservation strategies and for each particular case, according to the feedback process, you can make adjustments, as well as may be modified the incidence rates.

3.4. Performance standards

Once the initial conservation strategies were defined, the maintenance of the network should also be defined within the standards of performance previously determined, so they can be limits maximum or minimum.

3.4.1. Classification of pavement condition preset in the HDM-4.

By default, the Configuration section of the HDM-4 model [5] contains a classification of state of the pavements on the basis of the roughness, structural capacity, surface distress and friction parameters. Here is the set of tables that defines the classification for pavement types considered in the project:

Table 1 - Configuration of HDM-4 model

Surface irregularities: IRI (m / km)								
Road class	**Flexible**				**Rigid**			
	Good	*Fair*	*Poor*	*Very poor*	*Good*	*Fair*	*Poor*	*Very poor*
Trunk	2	4	6	8	2	4	6	8
Secondary	3	5	7	9	3	5	7	9
Tertiary	4	6	8	10	4	6	8	10

STRUCTURAL CAPACITY							
	Asphalt			**Concrete**			
	750	3000	7500	*Rupture module (MPa)*	3000	7500	15000
	structural number adjusted				Slab thickness *(mm)*		
Poor	1.50	2.00	2.50	4.00	160	170	180
Fair	2.00	2.50	3.50	4.50	170	180	190
Good	2.50	3.50	5.00	5.00	190	200	210

SCORING PAVEMENT BASED ON SURFACE DETERIORATION								
Deterioration	**Asphalt**					**Concrete**		
	Cracking *(%)*	*Added detachment (%)*	*Potholes/km*	Break edge *(m^2/km)*	Depth of ruts *(mm)*	Transverse cracking *(%)*	*Deteriorated joints (%)*	*Stepping (mm)*
New	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Good	0.00	1.00	0.00	0.00	2.00	5.00	0.00	1.00
Fair	5.00	10.00	0.00	10.00	5.00	20.00	10.00	2.00
Poor	15.00	20.00	5.00	100.00	15.00	30.00	20.00	4.00
Very poor	25.00	30.00	50.00	300.00	25.00	50.00	20.00	8.00

SURFACE RATING IN TERMS OF FRICTION BEARING				
	surface treatment		**Asphalt layers**	
	Macro-texture depth *(mm)*	*Friction coefficient (SCRIM 50km/h)*	Macro texture depth *(mm)*	*Friction coefficient (SCRIM a 50 km/h)*
Good	1.50	0.60	0.70	0.50

Regular	0.70	0.45	0.50	0.40
Slippery	0.30	0.30	0.30	0.30

3.4.2. IMT Pavement evaluation system

The Technical Publication # 208 of the IMT, Pavement Evaluation System version 1.0 [6], refers to a set of maximum allowable values of International Roughness Index (IRI), for different countries and types of road, according to the following table:

Table 2 - IRI permissible in other countries

MAXIMUM PERMISSIBLE IRI (m / km)			
Country	**National Highway**	**Free Highway**	**Toll Highway**
Belgium	3.5	2.5	2.0
Spain	3.0	2.5	2.5
France	2.8	2.0	2.0
Portugal	3.5	2.2	2.0
Italy	3.0	2.0	2.0

Reference values of friction coefficient for dry and wet pavement are reported, based on the "European Experience," and reproduced in the following tables:

Table 3 – Coefficient of minimum friction

MINIMUM FRICTION FOR DRY PAVEMENT				
Vehicle / Pavement	**C2, C3, C4**	**B1,B2**	**T2-S2 T3-S2**	**T3-S2-R2 T3-S2-R4**
Rigid/Hard	0.80	0.85	0.80	0.80
Flexible	0.80	0.85	0.85	0.85
Porous	0.75	0.85	0.85	0.85
Slurries	0.80	0.90	0.80	0.85
Seals	80.82	0.90	0.75	0.80
MINIMUM FRICTION FOR WET PAVEMENT				
Vehicle / Pavement	**C2, C3, C4**	**B1,B2**	**T2-S2 T3-S2**	**T3-S2-R2 T3-S2-R4**
Rigid/Hard	0.50	0.45	0.45	0.50
Flexible	0.50	0.50	0.45	0.45
Porous	0.45	0.45	0.40	0.40
Mortar	0.50	0.55	0.55	0.45
Seals	0.50	0.45	0.45	0.40

3.4.3. IRI scale, World Bank

Several World Bank publications include a figure as illustration of the IRI range variation for different types of pavement.

*3.4.4. AASHTO guide for pavement design**

The AASHTO guide for pavement design presents a set of serious descriptions for different types of pavement deterioration.

Therefore, according to network of analysis, it is required to define the performance standards that must be subject to the cycle of life. An example of this type of threshold is shown in the following table.

Table 4 – Threshold proposal for a road network

Indicator	Unit	Criteria
Average Irregularity (IRI)	m/km	≤ 3.0
Rut depth	mm	≤ 12 mm
Deterioration according to the LTPP manual	Seriousness level	Low
Total cracking	%	≤ 5
Cracking width	%	0
Detachment of aggregates	%	0
Potholes	Number	0
Border Breaking	m^2/km	0
Coefficient of friction (Mu Meter)	—	≥ 0.50
Depth macrotexture	mm	≥ 0.70
Structural capacity	—	The necessary according to a design to the fatigue.

Therefore, in order to the analysis considers these thresholds, it is necessary to define conservation strategies on the horizon of analysis, so that it meets performance standards.

4. CASE STUDY. DEFINITION OF THE CONSERVATION PROGRAM IN A NETWORK OF ANALYSIS IN THE HDM-4

4.1. Road network

In the road network all the features of each one of the segments within the network to be analyzed are defined; such as physical characteristics, alignments, traffic, capacity, structure, functional condition and state of deterioration of each stretch. The network consists of 69 roads of a state of the Mexican Republic.
As mentioned, the universe of roads that make up this network was divided into four groups according to their levels of heavy traffic, as shown in the figure below.

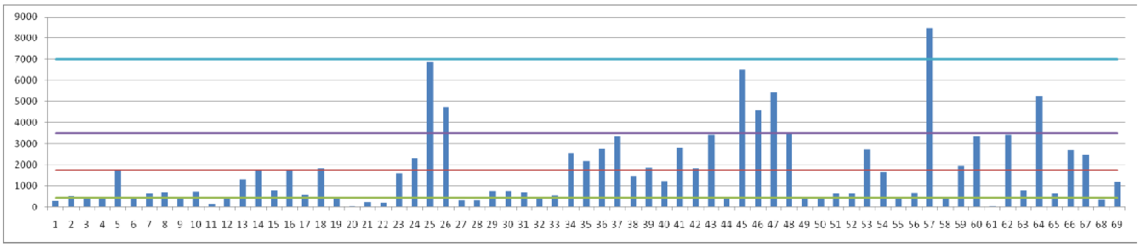

Figure 7: Distribution of road sections according to their levels of heavy traffic

The reason for considering the heavy traffic is because this type of vehicles causes more deterioration to the pavement. This grouping was made according to a statistical distribution and is considered only for the definition of conservation strategies, the volume of heavy traffic (types B and C) according to the following: Low Transit (below 450 heavy vehicles per day), Medium (450 to 1,500 vehicles daily heavy), High (1,500 to 3,400 heavy vehicles per day) and Very High (more than 3,400 heavy vehicles per day). This IRI, rut depth and Traffic (heavy vehicles) combination, generated different preservation strategies that are best suited to the importance of the road (traffic) and its maintenance requirement (IRI and / or PR).

4.2. Representative vehicle fleet

They are the physical characteristics of the different types of vehicles on the network; it serves as input for calculating vehicle operating costs.
The vehicle fleet that is proposed is based on the vehicles classification used in the Roads Data Book of the Directorate General of Technical Services of the Ministry of Communications and Transport (DGST); this classification includes seven types of vehicles, which in general terms are considered representative of the existing vehicle composition in the highways of the study.
The vehicle classification of the DGST includes the following types: automobile (A), bus (B), two-axle unit truck(C2) three-axle unit truck (C3), articulated truck with two-axle trailer (T3-S2) articulated lorry with three-axle trailer (T3-S3) and semi-articulated lorry with two axles and four-axle trailer (T3-S2-R4). The following table presents the specific models proposed to characterize each of the above types of vehicles.

Table 5 - Vehicle Fleet representative

Type of vehicle	Model
A	VW Bora 2009 model with 2.5-liter engine and manual transmission
B	9700 Volvo 2009 model D13 w / EGR 13L-435 HP Diesel Engine
C2	Dina 551 2001 model, 175 HP Caterpillar 3126B Engine
C3	Dina C3 661 2001 model, 250 HP Caterpillar 3126B Engine
T3-S2	International 9200i 2008 model with 435 HP Cummins engine and trailer with two shafts box 40
T3-S3	International 9200i 2008 model with 450 HP Cummins engine and three-axle trailer with box 40 '

T3-S2-R4	International 9200i model 2008 with Cummins 500 HP, trailer and towing two-axle 4-axle, two boxes of 40 '

4.3. Preservation Strategies

The alternatives to be applied to each stretch and be evaluated against a base alternative, in order to find the most profitable ones in economic terms, this profitability is obtained by comparing the benefits in savings in vehicle operating costs against the costs of investment conservation of each stretch or the entire network.
The information in these sets of data must exist within the HDM-4 to carry out an analysis of conservation program.
For the case in study, different reference values given for each road are considered. These values, depending on the road, are as follows, 3, 3.5, 4 and 5 m/km. That is to say, 4 different reference values in total, which were considered in the model as detailed below.
The measurements were obtained from the IRI to carry out the analysis, rut depth average, distress level of each road, deflections with HWD deflectometer, elastic modules, surface cracking, potholes, as well as volumes and traffic composition. Having a lot of information requires finding a way in which this accurately represents the network of highways and roadways in order to enter it to the HDM-4 model.
An option to enter information to HDM-4 is to take indicators that are representative for each route. With the gathered information and particularly with the IRI, the 69 tracks were divided into 443 segments with homogeneous characteristics of functional and structural condition, i.e., stretches that had a certain level of IRI and/or average rut depth (high or low) were separated, through a statistical process in which we had a representative value for the entire stretch.
By having the network divided into smaller sections, a more appropriate, efficient and convenient conservation can be assigned, depending on its condition of existing irregularity. The benchmark serves as a "detonator" to generate conservation interventions throughout the period of analysis. The combination of IRI, rut depth, Traffic (Trucks/heavy vehicles) and IRI reference have generated different preservation strategies that will be best suited to the importance of the road (traffic) and its requirement for maintenance (IRI and / or PR).

TDPA VEH PESADOS DIARIOS	ACCION INICIAL DE CONSERVACIÓN	CD	U	ACCIONES SUBSECUENTES PERIÓDICAS	CD	U
BAJO < 450	Fresado de 5 cm + carpeta de 5 cm para IRI > 3	$ 139.27	m2	Riego de sello para IRI > IRIref	$ 53.49	m2
MEDIO 450 - 1500	Fresado de 5 cm + carpeta de 5 cm para IRI > 3	$ 139.27	m2	Fresado + carpeta de 4 cm para IRI > IRI ref	$ 112.72	m2
ALTO 1500 - 3400	Fresado de 5 cm + Recuperación BEC 4% de 25 cm + carpeta de 8 cm para IRI > 4 o PR > 12	$ 293.23	m2	Fresado + carpeta de 5 cm para IRI > IRI ref	$ 165.82	m2
MUY ALTO > 3400	Fresado de 5 cm + Recuperación BEC 4% de 25 cm + carpeta de 10 cm para IRI > 4 o PR > 12	$ 341.96	m2	Fresado + carpeta de 5cm para IRI > IRI ref	$ 218.91	m2

BEC: Base estabilizada con cemento portland al 4 % de su PVSM, incorporando material de banco (grava) en un 15 %
IRI ref: Valor del Índice Internacional de Irregularidad Superficial máximo permitido para cada una de las carreteras o vialidades

Figure 8 – Final preservation strategies according to traffic

Figure 8 shows the different preservation strategies used in the analysis, these were defined to generate a very beneficial combination of technical aspects, e.g., the economic aspects; to fulfill the network behavior throughout the period and fit the budget to maintain it. The explanation of figure 8 is the following: according to the traffic level of the road in study (low, medium, high and very high) a preservation strategy was determined, i.e., the action of initial reconstruction and subsequent actions in the period of analysis within the project of the horizon. For this, the main consideration is the IRI of reference; before this is reached, the HDM-4 model triggers the conservation action to be executed. For the initial reconstruction actions, IRI values are considered as rut depth to define the performance of an initial action.

CONCLUSIONS

It is necessary to promote a culture of pavement management systems at all levels that manage or operate road networks, making a permanent collection of data on themselves that allow carrying out an adequate monitoring, as well as preservation planning.

For this it is necessary to use new technologies in the field of pavement evaluation, as well as computer tools that allow the handling of such plentiful information; is the case of management model HDM-4, which is a powerful tool for pavement management. Similarly, those responsible for road networks must establish the different performance parameters under which the same should be regulated.

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