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ROAD INFRASTRUCTURE QUALITY: ASSET MANAGEMENT AND SUSTAINABLE DEVELOPMENT

R. Solorio
Mexican Transport Institute, San Fandila, Queretaro, Mexico
rsolorio@imt.mx

B. Ortiz
Subsecretariat of Infrastructure, Secretariat of Communications and Transport,
Mexico, Distrito Federal, Mexico
bomantil@sct.gob.mx

J.M. Osio
General Directorate for Road Maintenance, Secretariat of Communications and Transport,
Mexico, Distrito Federal, Mexico
josio@sct.gob.mx

R. Vazquez
Federal Toll Roads, Bridges and Complementary Services (CAPUFE)
Cuernavaca, Morelos, Mexico
jrvazquezg@capufe.gob.mx

1. ABSTRACT

A description of the most relevant initiatives related to using asset management tools for ensuring the sustainable development of the Mexican federal road network is presented in this document. Firstly, the general characteristics of the Mexican national network are depicted, including total length, road class, pavement type, jurisdiction and length corresponding to toll and toll-free roads. Next, the organisational structure of the Mexican Secretariat of Communications and Transport (SCT) is presented, indicating those areas related to road preservation and development. The subsequent three sections contain descriptions of some of the most significant projects being deployed by areas of SCT to improve the decision-making processes on which the federal network maintenance and improvement are based. These comprise the following: i) HDM-4 applications within the SCT General Directorate for Road Maintenance; ii) A HDM-4-based Pavement Management System developed by Federal Toll Roads, Bridges and Complementary Services (CAPUFE), an entity decentralised from SCT which operates the majority of the federal toll roads; iii) An Integrated Road Infrastructure Management System being developed by SCT Subsecretariat of Infrastructure, aimed at addressing concurrently the various aspects of road management including maintenance, operational issues and project development. Following these descriptions, some potential limitations of the presented initiatives are pointed out, particularly the lack of a formal asset management conceptual framework.

2. THE MEXICAN ROAD NETWORK

According to the Mexican Secretariat of Communications and Transport (SCT) (DGDC, 2009), road assets of Mexico consist of 356,945 km of roads from which 120,498 km are paved and 236,627 km unpaved. Forty percent of the paved roads (48,319 km) make up the federal network which includes two lane and multilane roads that spread all over the Mexican territory. Federal roads are operated mainly by SCT though an increasing portion of them reaching 2,322 km in 2009 has been concessioned to private operators through different models of public-private partnerships. The remaining 72,179 km of paved roads (60%) correspond to subnetworks consisting almost completely of two lane roads that are under the jurisdiction of Mexican states. Unpaved roads correspond to local roads that provide access to small rural communities and consist of 167,877 km of gravel and earth roads (71%) and 68,750 km of dirt roads (29%). Although SCT still participate in some local roads programmes most of these roads are also administered by Mexican states.

Mexico’s federal road network is further divided into a primary and a secondary subnetwork. The former is 31,147 km length and groups roads connecting state capitals and major cities, as well as ports and border crossings. The secondary subnetwork is made up of 17,172 km of roads of local and regional significance that also give access to the primary subnetwork.

Within the primary subnetwork there are 19,245 km of roads that define altogether the main corridors of the country. These road axes include most of the four or more lane roads available in the network, whose length came to 11,616 km in 2007 (Martínez et al., 2009). Road corridors also account for almost all of the toll roads length (7,122 of 7,698 km or 92.5%). Figure 1 illustrates the classification of the Mexican road network. The main road corridors are portrayed in Figure 2.

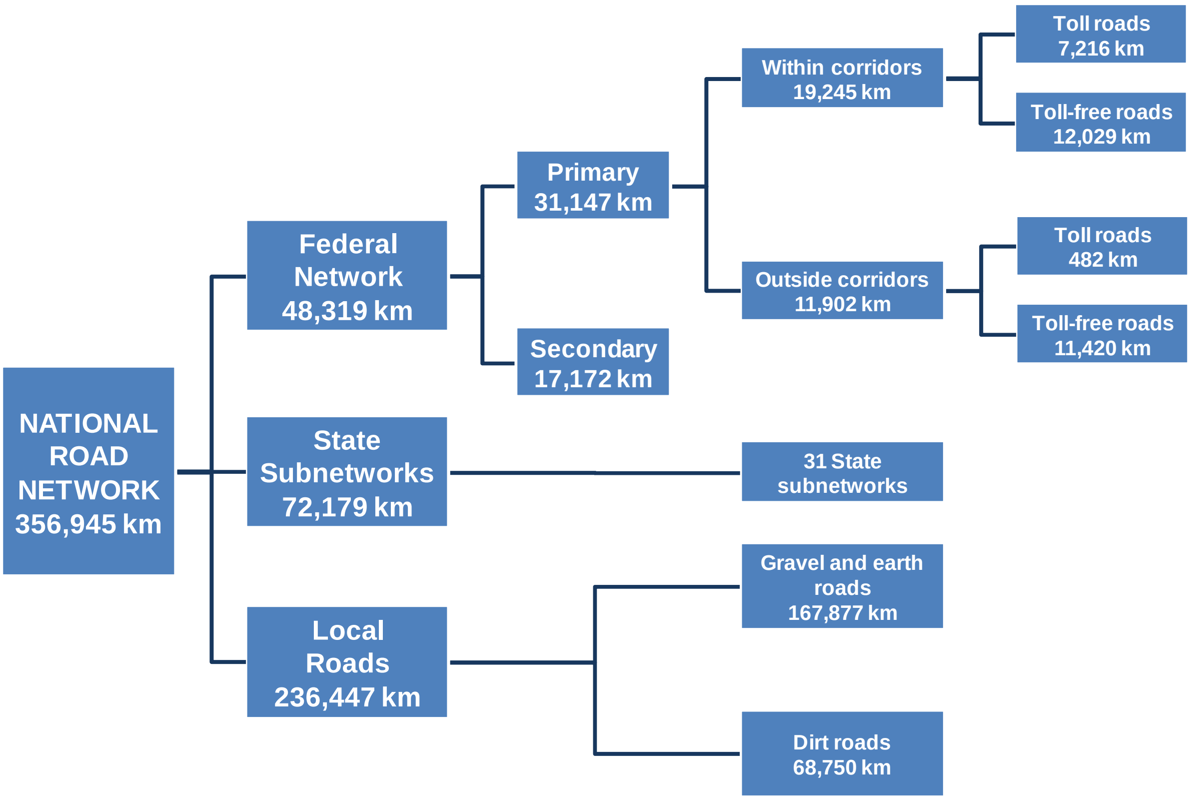

Figure 1 - Classification of the Mexican Road Network (DGDC, 2009).

Figure 2 - Main corridors of the Mexican federal road network (DGDC, 2009).

3. SCT ORGANISATIONAL STRUCTURE

The Secretariat of Communications and Transport (SCT) is the agency of the federal government responsible of performing road operation and management functions. SCT duties extend far beyond these functions and encompass all activities related to policy making, planning and regulation for the development of infrastructure and the provision of services in both the transport and telecommunication sectors. For the specific road subsector SCT acts as the maximum authority in providing standards and technical advice.

SCT organisational structure includes a number of subsecretariats, coordinations, directorates and decentralised units from which the most relevant for that concerning road management is the Subsecretariat of Infrastructure (SI). This entity is organised according to the structure shown in Figure 3.

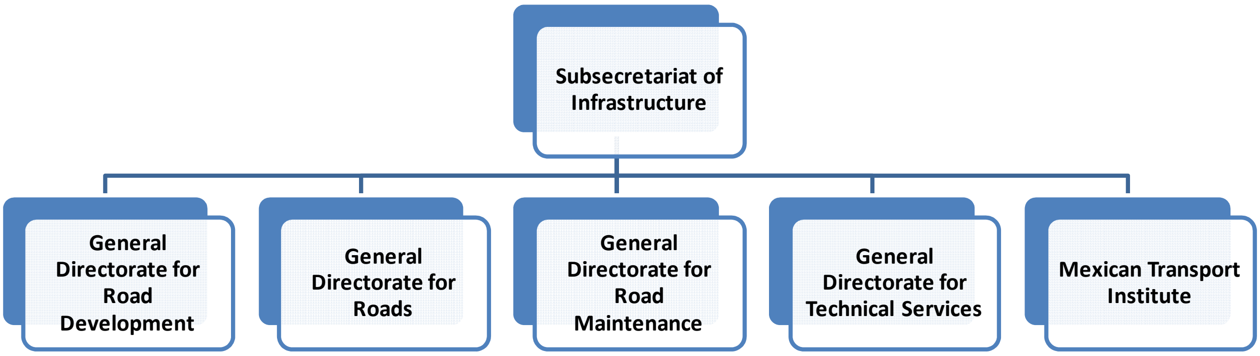

Figure 3 - Structure of the SCT Subsecretariat of Infrastructure.

The functions of each of the subunits represented in the above chart can be summarised as follows (SCT, 2010):

General Directorate for Road Development (DGDC): Plan the strategic development of the federal road network, conduct the bidding processes required by law to grant concessions for operating road infrastructure and supervise the performance of concessionaires.

General Directorate for Roads (DGC): Manage new road projects; put forward projects for modernising road corridors; improve accessibility to urban areas through proposing the construction of bypass and access roads; participate in planning and monitoring new construction, reconstruction and maintenance of secondary and local roads.

General Directorate for Road Maintenance (DGCC): Maintain the federal toll free network by identifying, bidding and supervising the public works necessary to provide the best possible level of service for promoting the country’s development.

General Directorate for Technical Services (DGST): Provide a broad and multidisciplinary technical support for planning, designing, projecting, constructing, maintaining and operating the national road network using state of the art technologies.

Mexican Transport Institute (IMT): Support a comprehensive development of the transport sector by performing research and technological innovation studies, formulating technical standards and promoting training activities and graduate education programmes (IMT, 2010).

Also relevant for the federal network management is the decentralised unit known as Federal Toll Roads, Bridges and Complementary Services (CAPUFE), which operates 4,128.4 km of federal toll motorways (CAPUFE, 2009), that is, 54% of the total length of federal toll roads. As with any other federal road operator, CAPUFE activities are monitored by the SCT Subsecretariat of Infrastructure.

In the last decade, SCT has promoted the sustainable development of the federal network as a whole by two main courses of action: i) Identifying and implementing public-private partnership models to complement the insufficient public investments available for preserving and further developing the network; ii) Requiring its dependent General Directorates as well as CAPUFE and private concessionaires to use reliable data and road management tools in supporting task such as:

- Evaluating the economic and financial feasibility of road projects.
- Formulating preliminary maintenance programmes for both public and private operated roads.
- Assessing the performance of road concessionaires.
- Estimating the life-cycle maintenance needs of new construction or improvement projects in public-private partnerships.
- Preparing the terms of reference for bidding new road concessions in different public-private partnerships.

SCT activities related to support the use of road management systems include the following:

a) For decades, the General Directorate for Technical Services (DGST) have been collecting information about the volume and composition of traffic in federal and state roads. Originally meant to support the formulation of road construction or improvement projects as well as the analysis of operational problems, this information is now critical for any initiative dealing with road management.

b) In the late nineties, the General Directorate for Road Development (then the SCT Unit for Toll Roads) starting measuring annually both IRI and Rut Depth in the whole federal toll road network, in an effort to ensure that operators were meeting the agreed performance criteria. These measurements have continued uninterruptedly since then and have been complemented in recent years with the calculation of vehicle operating costs and the procurement of continuous panoramic photographs of the roads being measured.

c) Both the General Directorate for Road Maintenance (DGCC) and CAPUFE have developed pavement management systems based on HDM-4. These might be the most significant experiences in deploying infrastructure management systems in the country and therefore they are summarised in sections 4 and 5.

d) The Subsecretariat of Infrastructure (SI) itself has recently started a project for developing an Integrated Road Infrastructure Management System as part of SCT efforts for modernising the federal road network. This system is presented in some detail in section 6.

4. HDM-4 APPLICATIONS WITHIN DGCC

As indicated in section 3, the General Directorate for Road Maintenance (DGCC) is the area of SCT responsible of maintaining the federal toll-free network. Assets managed by this entity include 40,509 km of roads that DGCC classify as follows (Osio, 2010): i) Roads making part of main corridors (9,887 km, see Figure 2); ii) Primary subnetwork outside main corridors (13,541 km); iii) Secondary subnetwork (17,081 km). The replacement value of the federal toll-free network is estimated in $US 45.2 billion.

The SCT started the formal application of road management systems in 1993 when DGCC implemented the Road Maintenance Strategies Simulation Model (Simulation de Stratégies d'Entretien Routier, SISTER). This model was used for more than 15 years to compare the outcome of various budget scenarios in terms of medium to long term pavement performance and to formulate annual and multiannual work programmes.

In year 2001 DGCC started a process for abandoning SISTER in favour of the HDM-4 system supported by PIARC. Reasons for discontinuing SISTER included its use of some non-standard and subjective road condition indicators along with a restrictive licensing schema. This process reached a major milestone in 2007 after a pilot study conducted in several states produced the following findings: i) Work programmes derived from HDM-4 better address road maintenance needs; ii) More reliability can be conferred to HDM-4 results on resource optimisation when compared to SISTER's; iii) Options for alternatives definition and analysis setup are more versatile in HDM-4 while overall calculations are faster.

Critics of HDM-4 often refer to its huge data requirements which include hundreds of data items for a single run. DGCC dealt with this concern taking into account HDM-4 sensitivity as described in the system's documentation (Bennet et al, 2000) as well as in the results on the same subject reported by the Mexican Transport Institute (Solorio et al., 2004). From the revision of these documents it was concluded that the following data must be always collected to obtain meaningful results from HDM-4: On one hand, road inventory, traffic volume and composition, International Roughness Index (IRI), rut depth, surface distresses, pavement deflections, thickness of pavement layers and climate parameters; on the other hand, general information about the vehicles included in the vehicle fleet being considered and unit costs of the resources required to operate each vehicle. All these data are collected annually. IRI, rut depth and pavement deflections are measured with high performance equipment by means of contracts granted to specialised firms (Figure 4); traffic information is extracted from the reports produced by DGST; the remaining information is gathered directly by DGCC.

DGCC analyses with HDM-4 do not take actual road sections as input; instead, they use aggregate road lengths resulting from a network matrix that, in turn, is obtained by classifying roads into categories defined for key parameters such as the following: traffic, IRI and pavement deflexion (3 categories for each); road class (3 categories: corridor, primary and secondary). A number of predefined maintenance strategies are technically and economically evaluated for these virtual sections using HDM-4 which produces a preliminary work programme that includes type of work, section location, cost and indicators of economic feasibility. DGCC definitive work programmes for years 2008 to 2010 were derived from these HDM-4 outputs.

Figure 4 - Pavement deflections being measured with HWD equipment in a toll-free federal road (Osio, 2010).

An additional software program called Pavement Information System (SIP) has been specially developed by DGCC to support the systematic application of HDM-4. This software is used for managing all the information required, generating HDM-4 input files and retrieving HDM-4 results to produce a set of custom reports specifically designed to support the DGCC decision making processes.

The combined use of the SISTER and HDM-4 models have allowed DGCC to increase the percentage of roads in good to fair condition from 43% in 1994 to 80% in 2008, as shown in Figure 5. Another major benefit from these developments relates to the formal adoption by DGCC of an effective road management cycle as part of its institutional practices thus building up on the sustainable development of the federal toll-free network. However, this sustainability cannot be achieved if the available resources are insufficient to implement the programmes delivered by the road management process.

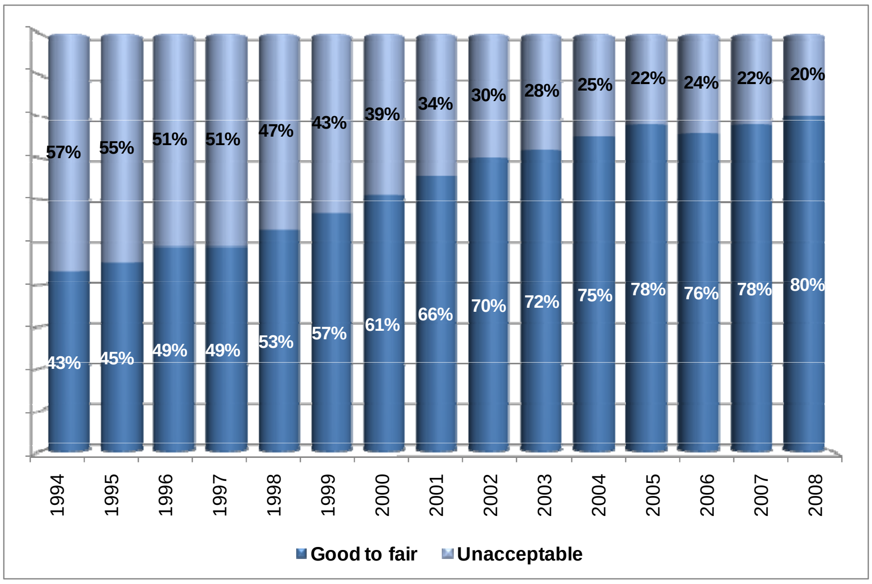

Figure 5 - Evolution of the federal toll-free network condition from 1994 to 2008.

In this sense, the public funds available for maintaining the federal toll-free network have been historically scarce and subject to a great deal of variability (up to 50% between the maximum and minimum budget allocations). To address this issue SCT has proposed, as part of its initiatives to attract private investments, a new model of public-private partnerships called Multiannual Road Maintenance Contracts (CPCC). In addition to prescribe time frames of 5 to 10 years, this kind of contracts integrates the various activities required for maintaining all road components (pavements, structures, road signals, etc.) and consider all maintenance types: routine, periodic and reconstruction. The performance of concessioners will be evaluated through a set of quality of service indicators.

DGCC have grouped CPCC contracts in 31 packages (one per state). The total length involved amounts to 16,203 km (40% of the toll-free network length) and includes mainly sections belonging to road corridors and the primary subnetwork. The economic viability of CPCC projects was again determined using the HDM-4 model.

CPCC deployment has formally started with a pilot package corresponding to the state of San Luis Potosi whose invitation to bid was published last march.

5. CAPUFE PAVEMENT MANAGEMENT SYSTEM BASED ON HDM-4

As mentioned in section 3, Federal Toll Roads, Bridges and Complementary Services (CAPUFE) operates 4,128.4 km of federal toll motorways which account for 54% of the total length of federal toll roads. These motorways must provide high performance standards in terms of user comfort and safety, which turns the delivery of reliable maintenance programmes into a critical issue.

A total of 3,757.6 km of the road network operated by CAPUFE (91%) is owned by the National Infrastructure Fund (FONADIN), a trust fund created by the federal government to support the participation of the private sector in developing infrastructure projects for telecommunications, transport, water supply, environmental care and tourism. The National Bank of Public Works and Services (BANOBRAS) was designated as the FONADIN trustee and, as such, granted a contract to CAPUFE for operating the length of roads specified above. Until 2008 these road assets were owned by another federal trust fund known as FARAC.

From 2004 to 2006 CAPUFE carried out a pilot study funded by BANOBRAS and technically supported by IMT which dealt with the development of a pavement management system based on Geographic Information Systems (GIS) and the HDM-4 model. The main outcomes from this study were: i) A draft pavement management cycle for the FARAC network; ii) A database layout specifically designed for storing inventory and condition data of motorway networks; iii) Algorithms for processing traffic information, segmenting motorway sections based on pavement condition indicators and obtaining homogeneous segments; iv) A computer programme (running on a SIG platform) for generating homogeneous segments ready to be imported from HDM-4; v) Terms of reference for bidding and contracting road condition surveys; vi) A preliminary maintenance programme generated with HDM-4 for a subset of three motorways specifically addressed in the study.

The pilot study also produced two key findings:

- HDM-4 is a suitable tool for identifying adequate maintenance options for toll motorways though benefit-cost analyses may not be as relevant as for other road networks since high performance criteria should always be met in this case.
- A SIG platform is inappropriate to develop pavement management system software as it requires a lot of computer resources to provide the numerous functions of geographic information systems. Much of these options are useless for pavement management applications.

In 2008 BANOBRAS, CAPUFE and IMT signed a new agreement to develop a pavement management system for the FONADIN network based on HDM-4. This new project had the following objectives: i) Refining the pavement management cycle; ii) Gathering inventory, traffic, climate and historical information for the whole FONADIN network; iii) Contracting and supervising the collection of an initial series of condition data; iv) Deploying a road database for the FONADIN network; v) Defining a set of alternatives to be analysed with HDM-4; vi) Designing procedures to retrieve HDM-4 results and use them in producing the outputs required by CAPUFE and BANOBRAS to support their decision making processes; vii) Obtaining preliminary work programmes with HDM-4; viii) Developing a customised pavement management software capable of interfacing with HDM-4.

The project has been scheduled for completion by the end of 2010 so it is currently in its final stage.

The operation of the system is based on an annual pavement management cycle that consider the functions of the main stakeholders (i.e. CAPUFE, BANOBRAS, SCT and contractors) to go through the main steps defined in the cycle: data collection, database update, condition assessment, policy review, evaluation of treatment options, decision making, projects formulation and works bidding and contracting.

To address the concerns related to HDM-4 data requirements, an approach similar to that used by DGCC has been employed (see section 4). It must be noted that the system consider the collection and storage of data that, though not necessary to perform HDM-4 runs, could be very useful in various steps of the management cycle such as condition assessment and evaluation of treatment options. This additional data comprise the whole set of standard indicators used internationally to depict the pavement surface damage (e.g. fatigue cracking or corner breaks), deflection readings for all sensors of FWD equipment, panoramic photographs of roads with total land requirement and geographic features for representing a wide variety of spatial objects including the motorways. Table 1 summarise the data stored in the CAPUFE Pavement Management System database, indicating the source of each information subset and the measurement equipment used when applicable.

Table 1. Summary of data stored in the CAPUFE Pavement Management System database

Information subset	Data source	Equipment
Traffic	DGST reports	
IRI and rut depth	DGDC surveys	Laser profilometer
Surface distresses	CAPUFE surveys	High resolution cameras
Pavement deflections	CAPUFE surveys	Falling weight deflectometer
Pavement structure	CAPUFE surveys	Ground penetrating radar
Climate parameters	Climate catalogue prepared by IMT	
Historical data	CAPUFE records	
Geometric design parameters	CAPUFE records	
Vehicle Fleet Data	IMT records	
Friction parameters	CAPUFE surveys	
Geographic features representing roads	CAPUFE surveys	Global positioning system
Other geographic features	CAPUFE records and public sources	
Road panoramic images	CAPUFE surveys	Video system

Some of the most important system building blocks were based on pilot study outcomes, including the draft management cycle, database layout, algorithms for processing traffic information and road segmenting, and terms of reference for contracting condition surveys.

In that concerning HDM-4 both the alternatives evaluated and the analysis schema were refined.

In the scope of the CAPUFE pavement management system, the application of HDM-4 consists of running life-cycle programme analyses for road networks derived from the segmentation of a given FONADIN section using the system algorithms. All segments are assigned the following four standard alternatives: i) Routine maintenance (base alternative); ii) Technically optimum alternative; ii) Differed maintenance alternative; iv) Deterioration-reconstruction alternative. Once the analysis is executed, HDM-4 results for each alternative are retrieved in order to generate weighted averages of condition parameters and calculate economic indicators for the whole section. The recommended preliminary work programme is the set of works corresponding to the application of the technically optimum alternative for all section segments. Equivalent preliminary work programmes are assembled for the other alternatives so that different courses of action could be selected if necessary.

HDM-4 application is supported by the pavement management software developed as part of the project. This software performs the following functions:

- Database management.
- HDM-4 data pre-processing, i.e. creating HDM-4 road network and programme analysis import files.
- Interactive road data query for all information stored in the system database.
- HDM-4 data post-processing, i.e. HDM-4 results retrieving to calculate technical and economic indicators and to allow users to assemble the preliminary work programme by combining results for all alternatives considered and by adjusting the execution year of each particular work. New HDM-4 runs may be generated repeatedly to evaluate the technical and economic feasibility of the modified programmes.
- Reports generating.

The pavement management software has a visual user interface based on “workspaces”. Users employ these workspaces to add views relevant for each of the system functions described above. For instance, views related to road data query include tabular, graphical and geographic representations of data which may be combined with panoramic images. These views are always synchronised according to kilometre posts so that the user may conduct a virtual inspection of the road. Concerning HDM-4 data post-processing, available views comprise a number of graphics for representing costs, benefits and technical performance of the evaluated alternatives, as well as a visual interface to modify work programmes. A typical road data query workspace is shown in Figure 6. Figure 7 illustrates the user interface for programme adjustment.

6. SI ROAD INFRASTRUCTURE MANAGEMENT SYSTEM (SGIC)

The precedent sections illustrate two of the various efforts carried out by SCT entities and other organisations to implement asset management tools for rationalising the allocation of resources to federal road maintenance and improvement projects. These efforts have typically included data acquisition, implementation of a road database and development or adaptation of analysis tools. Evidently, each agency must employ analytical tools that are appropriate for the particular subnetwork they operate; however, uncoordinated data collection and information management may lead to dissimilar procedures, duplicated tasks, resource wasting and, ultimately, may put at risk the sustainability of the management process for the federal network as a whole.

Figure 6 - CAPUFE pavement management software: workspace for road data query.

Figure 7 - CAPUFE pavement management software: interface for programme adjustment.

In addition to the specific problem outlined in the previous paragraph, it must be noted that there are few developments or projects addressing the management needs of road components other than pavements, like bridges, tunnels or slopes. Similarly, other aspects of network operation and development including traffic management, road safety, customer service, project management or construction supervision have not been dealt with in a consistent and integrated manner.

Derived from the above issues the SCT Subsecretariat of Infrastructure (SI) has proposed the development of a Road Infrastructure Management System (SGIC) based on the following premises:

- The primary subnetwork of the Federal Road Network (see section 2) constitutes a strategic component of the national road system and thus it must be given priority in modernising all processes related to planning, construction, maintenance and management. Consequently, the implementation of SGIC will focus on this subset of the federal network.

- SGIC operation must rely on a single source of information so a central road database supporting its operation must be deployed. Since a comprehensive management of the network requires taking into account the location and spatial coverage of each road section, its relations with other transport modes and the effects of the environment on its physical condition, the system database should be implemented using Geographic Information Systems technology.

- To ensure the consistency of the overall management process and avoid duplicity, all stakeholders including SCT entities, road operators and contractors should use the SGIC central database as a primary source of information to support their internal processes related to the operation, maintenance and development of the federal network.

- A number of specialised management systems are required as part of SGIC. Though a detailed analysis must be conducted to determine the set of systems that best align to SGIC objectives, at first a need for the following systems have been identified:

  - Inventory management. Refers to procedures and tools for managing the information related to the physical characteristics and georeferenced location of every single element of the road network, including pavement sections, bridges, drainage, tunnels, signals, slopes and total land requirement.

  - Maintenance management. These comprise systems for pavement, bridges and structures, tunnels and slopes. Concerning roads operating under public-private partnerships, these systems are aimed at providing information about compliance with the performance requirements. For roads operated by SCT entities, the systems will help SI ensuring the best use of the available funds. For SI, management systems should supply information about the maintenance and improvement needs for the whole federal network independently of the entity responsible of each particular subnetwork. Likewise, these systems should provide indicators of the overall performance of the network.

  - Safety management. Concerning this particular system, SI is already working with the International Road Assessment Programme (iRAP) and IMT to define mechanisms for applying in Mexico the methodology developed by this international organisation.

  - Bridge monitoring and inspection management. Since bridge failures may have significant effects in the safety and connectivity of the federal road system, a set of particular facilities and tools for the systematic procurement of bridge condition data should be an integral part of the management system being proposed.

- Road operation management. This system is intended for assessing permanently the level of service offered by roads in order to generate statistics and behaviour patterns that support the decision making process. It comprises aspects such as traffic management, signal management and provision of user support services ranging from road-side assistance to ITS systems.

- Performance indicators management. A system is required for monitoring all indicators currently used for measuring the performance of road concessionaires in the various public-private partnerships implemented by SCT. Compliance verification, report generation and alarm triggering are among the outputs expected from this system. Such outputs should be integrated in a control panel allowing decision makers to know at any time the current status of any concessioned road section.

- Project management. Refers to a set of tools for assessing the status of a road project at any stage in order to identify actual or potential problems.

- Construction management. Using document management tools, this system should help monitoring road works from the beginning of the bidding process to works delivery.

This set of systems is intended primarily to help SI keep track of ongoing programmes properly by generating the information needed at the managerial and operational levels to take action promptly and confidently. They also seek to support the activities of SCT entities involved in road management and development by providing them with reliable information and analysis tools. Systems already in place are not supposed to be replaced by SGIC subsystems; instead, they are expected to align to a common framework, providing the information required by institutional workflows. Not all of the proposed subsystems must be developed from scratch. A great deal of work has already been done which may be leveraged through integration efforts.

- Data required by SGIC subsystems and existing management systems should be collected centrally in order to guarantee that all information needed is procured, avoid duplicity, optimise resource use and apply measurement and processing standards. Experiences consisting in DGST gathering traffic data for the whole federal network and DGDC measuring IRI and rut depth for the federal toll network have proved beneficial for all users of that information. Taking into account these experiences it is recommended that DGST concentrate all data collection duties in the future.

Figure 8 depicts the general structure of SGIC.

A private consultant will be granted a contract to help in the process of developing SGIC. This process has been divided into three main stages: i) Initial stage, aimed at knowing in detail the efforts carried out within each area of SI, as well as their current needs, in order to agree in a formal framework for SGIC; ii) Design and development stage, in which the consultant will design and develop the system based in the agreed framework, producing the required documentation to allow for the operation of the system by the intended users; iii) Implementation stage, wherein the consultant will be working together within specialists of each area to deploy the relevant components of the system. The above process is depicted in Figure 9.

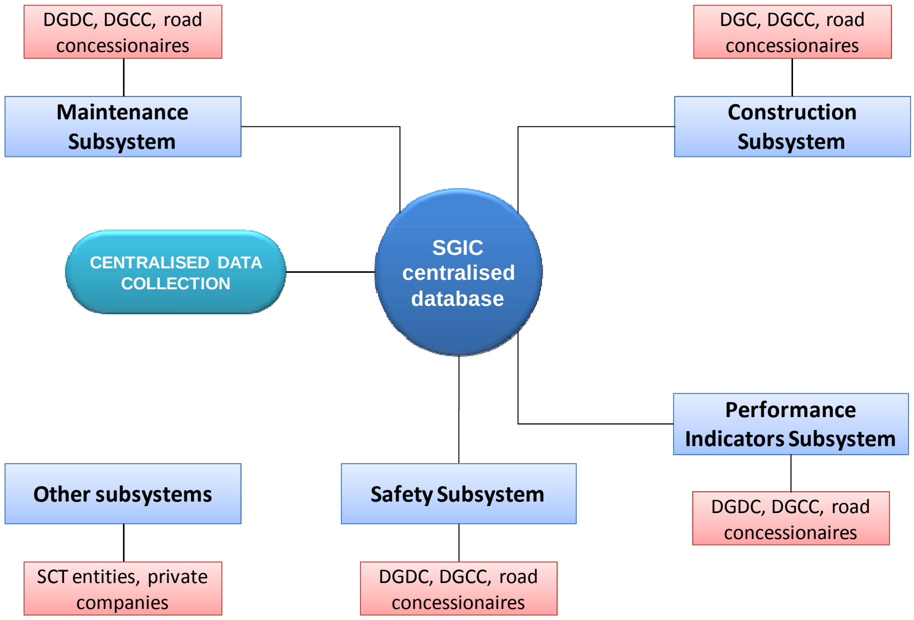

Figure 8 - General structure of SGIC.

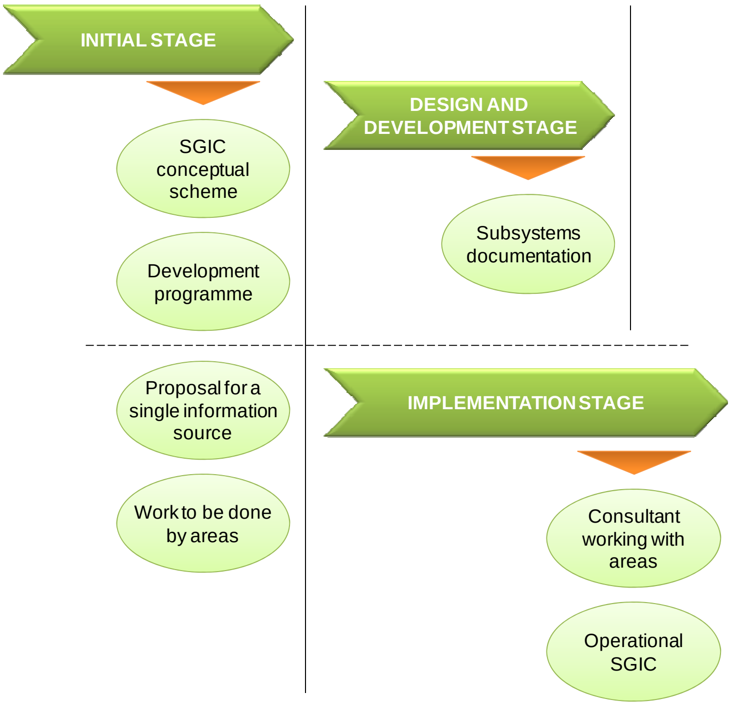

Figure 9 - SGIC development process.

7. POTENTIAL LIMITATIONS OF CURRENT DEVELOPMENTS

Developments described in sections 4 to 6 undoubtedly represent major steps in moving from an empirical approach to a formal framework for road management. However, a number of potential limitations exist which might prevent those developments from fully succeed. These include:

a) Road asset management is not being used as a conceptual tool. As a result, the importance of aspects such as top management commitment, organisational change, strategic planning and alignment of information flows to actual workflows might be underestimated.

b) There is an evident lack of Mexican standards related to measuring equipment, data collection, condition assessment and road inventory. Therefore, the implementation of road information systems producing consistent datasets could be difficult to achieve.

c) Human resources in road management and transportation asset management are scarce. At the same time, undergraduate and graduate programmes in highway engineering generally do not include those topics as regular subjects. This has resulted in a technological dependence that may be difficult to overcome in the near future thus conditioning the development of management systems.

d) Road management systems are still regarded by some stakeholders as a secondary issue, though this situation has been changing in recent years. Until these systems are not fully assigned a high priority, the flow of resources needed for their implementation will remain limited.

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