IMPLEMENTATION OF A BRIDGE MANAGEMENT SYSTEM IN GUATEMALA – CENTRAL AMERICA

J. Galicia[1], D. Mendoza[2], T. del Carril [3], G. Berditchevsky [3] , M. Mendoza[3], E. Lara[3], J. Fazio [3], J. F. Cronenbold [3]

1. ABSTRACT

At the present time, diverse bridge management systems (BMS) are implemented in different road agencies. It is of general k nowledge, that these systems usually have similar databases and evaluation processes which are based in the veracity and objectivity with which field information is gathered and evaluated.

Taking in consideration that developing countries have precariou s or inexistence inventories, and reduced technical and human resources, a reliable BMS was developed for Guatemala based on the following objectives: a) the creation of a reliable physical inventory of the bridges using local human resources with basic tr aining, b) to verify the geodesic location of the bridges in the road network, c) to easily revise and update the system data base, d) to generate through the use of the system reliable annual necessities with regard to maintenance activities and work quan tities, providing prioritized investment programs for six -monthly or annual periods based on the allocations of costs estimated for works required for each bridge or group of bridges, e) To issue inspection programs to be done in the future in order to con trol the evolution in time of parameters enabling qualification of structures, f) to identify potential risk bridges, and facilitate the definition of solutions for the road network, for handling these sites in the event of bridges collapses and the occurr ence of natural disasters. These objectives, were fixed by the Ministry of Communications, Infrastructure and Housing (MICIVI) through the General Road Directorate (DGC) of Guatemala.

The work done includes the development of a project with the meeting of the outlined demands, using innovative methodologies for field inventory using video filming and GPS inventory equipment, Video TV office data processing, and a new approach towards system development of a BMS for worldwide use based on the Fuzzy Sets.
The first stage of the project, included the inventory and data processing of 840 bridges along the paved road network, and the introduction of the bridges' inventory into a road GIS management network. The latter, for the alphanumeric and visual data bas e management, as well as network analysis in the event of road and bridges collapses. The second stage of the project was focused on the system analysis and the estimate of maintenance works activities for planning proposes.

2. INTRODUCTION

Guatemala is a country located in Central America. The country is mainly mountainous and has two very well defined seasons: the dry and the rainy. The rainy season in Guatemala lasts for approximately 6 months with precipitation levels in some areas of 4,000 mm/ye ar. Guatemala is also located in an area of high seismic and hurricane risks, where in the recent years Hurricane Mitch left serious damages to the road infrastructure.

Guatemala has a road network of approx. 5,000 Kms. of paved roads, and 20,000 Kms. of unpaved roads. Because of its mainly mountainous landscape the location of bridges along the network is dense, reaching 840 structures (with spans larger than 5 meters) only on the paved network. The bridges' network was mostly built during the '30 and ´60 decades, so were load designed for a traffic lighter than the one currently driving the country. Along the main road axes, mostly steel trussed bridges of different type are constructed (deck, pony, through truss).

Until this system was implemented, the situation relative to knowledge and management of the bridge network was as follows:

1. There was no bridge inventory.
2. The blueprint file was disorderly, although complete and well preserved.
3. There were no plans for maintenance, repair and rehabilitation of works. The annual planning of maintenance works was inexistent, and the local bridge experts was reduced to a number of specialized engineers from the private sector.
4. It was not possible to forecast the amount of funds necessary for maintaining the bridge system in good functioning status.
5. The Roads Authority did not have personnel to assign to solution of problems. The maintenance of bridges was mostly emergency repairs made through the Unit of Contract Maintenance (COVIAL). Personnel dedicated to bridge maintenance could not cope with emergencies and repairs arising unexpectedly.
6. When necessary to work on a bridge, it was not possible to find corresponding blueprints in the files.

In general, the conjunction of the facts mentioned above, made the bridges' network very vulnerable, having some bridge collapses every year. For example, in 2001 there have been four collapses, which mostly affected the two main highways of the country. These are highways linking Pacific ports with those of the Atlantic, going through the Capital of Guatemala.

To respond to the objectives fixed by the MICIVI-DGC, an inventory system was implemented, on the paved road network, using existing methodologies but with specific applications for bridges, for the purpose of having trustworthy field data and impartial evaluations in the office. Also, efforts were made to develop a computer application for easy access and handling through a GIS, that could allows the reliable analysis of diverse alternatives of programming, planning, execution and control of maintenance works, as well as for handling potentially risky areas.

3. FIELD INVENTORY

Field inventory technicians were train to identify bridges and bridges environment structures' damages, and were guided to use a bridge inventory manual. The field inventory was performed with the use of videotape cameras. The filmed information was accompanied with voice data recorded by the field technician. The latter supplemented the visual data base with particular aspects that escaped the filming, such as physical dimensions of the inventoried bridge, extent of damages, and the dimension characteristics of the structure, river side, bridge access, and drainage systems.

The filming was accompanied by gathering geodesic coordinates that marked the physical location of the bridge, and which were taken by means of global positioning systems receivers (GPSs). With this tool each bridge was located on the country's road map. The gathering of geodesic coordinates helped to attach the information to a GIS already developed for road analysis, allowing to view the bridges' filming along the road network.

The field crews were comprised of two technicians (one that filmed and one that managed the GPS), an assistant in charge of making physical measurements of the bridges' width, approaches and the drainage elements, and a driver. The vehicles were equipped with a videotape camera, a GPS, a portable computer, and metric tapes.

4. OFFICE DATA COLLECTION

The physical information about the bridges and their condition made through filming, once obtained, was processed in the office by means of visualization in individual televisions and studying narrative comments about pictures.

The Bridge Management System (BMS) implemented to conform to and process the bridge inventory database was developed based on the Fuzzy Sets.

The office work included the generation of topologies for the ARCVIEW Geographical Information System (GIS), digitalization of videotapes, establishment of relationships in the GIS (through the road net map), and alphanumeric and filmed database of the management system.

The database collection was made under the constant supervision of a bridge engineer with the intent of that the data collected in each capture module in which the technicians are located has a unified evaluation criteria so as to minimize the subjectivity of entered data.

5. FUNCTIONAL ORGANIZATION OF THE BMS

It is worthwhile underlining that this is an open system, in the sense that inventory and evaluation variables may be modified after a period of functioning during which the General Roads Authority will acquire greater knowledge of particular aspects improving usage and will be able to adapt their planning to proper procedural forms.

5.1 Generalities

The Bridge Management System is based on linked actions of different modules and elements, as follows:

a) A Data Base; b) Inventory Module, c) Evaluation Module, d) Costs Module, e) Priority -setting Module, f) Reports Module, g) Planning Module

The Management System executes a great amount of operations within the scope of each module, based on data contained and updated in a Relational Data Base based on the Microsoft Access system.

Variables managed for priority -setting of investments in bridges are of different types, and many of them – such as those later described as ***evaluation variables*** – are assigned uncertain values.

Considering the uncertainty per se of evaluations, along with the great amount of variables determining condition state and vulnerability of a bridge, plus the fact of considering broad type variables – usually not measurable – it has been opted to implement an algorithm based on so - called Fuzzy Logic.

The following is a brief explanation of some general concepts of Fuzzy Logic, with the only propose of which is to show the criteria used by the technique to obtain conclusions based on incomplete data of uncertain value.

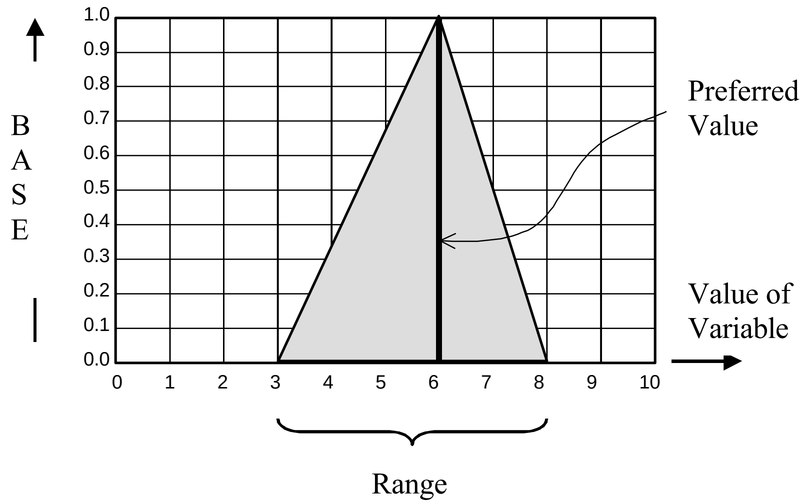

Figure 1

Each value is defined by a fuzzy number such as that represented in the following figure, where it may be seen that a ***Preferred Value*** and a ***Range*** are adopted, determining the uncertainty established upon consigning a value to a certain variable. In the case of the attached figures, a fuzzy number has been represented with a preferred value of 6 and a range of 5 (-3 and +2). This number should be interpreted as a variable with value 6 with maximum base, but may be considered with value 5 with a 0.7 base, with value 4 with base 0.35 or with value 7 with a 0.5 base.

This value type is assigned by the System to each variable, in which each of them has been predefined with literary values – these being the ones consigned by experts during evaluations. For example, the group of values possibly adopted by, are Very Good, Good, Fair, Bad , Very Bad (VG,G,F,B,VB).

Based on values qualified on the basis of these numbers and applying Fuzzy Logic rules, it is possible to carry out all operations.

The ***influence*** of each value on the final result has also been established by means of fuzzy numbers, which imply concepts, such as, for example: " Railing condition has ***very little influence*** on structural stability".

The following is a description of characteristics of modules and elements making up the Bridge Management System implemented for the General Roads Authority.

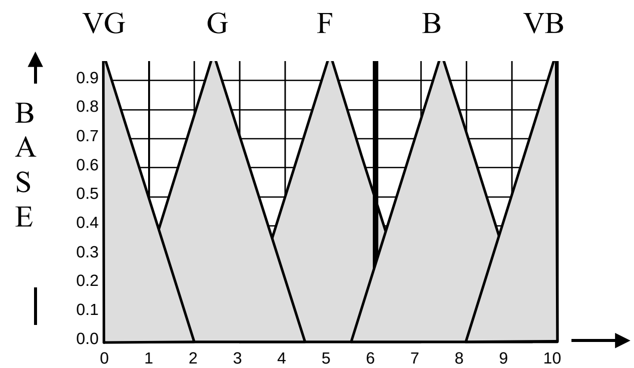

Figure 2

5.2 Inventory Module

This module stores values of so-called Inventory Variables, which may be classified in different ways.

In the first place, they may be distinguished as per their origin, considering those of Administrative type (such as designations of roads or roads' sections) and those of physical type (such as road width or foundation level), that is, which express the real physical characteristics of the structure or the localization of itself.

Secondly, it is possible to differentiate between Inventory Variables, those which are Fixed (such as total length or width of the road), from those which are Variable and may be modified during useful life of bridge, for instance due to morphological modifications of a riverbed or execution of minor works (such as replacement of railings or improvement of visibility at bridge entrance).

Thirdly, the most important classification for operating the Management System, is that used for qualifying them in the following aspects:

a) General; b) Geometric; c) Hydraulic; d) Structural; e) of Economy and Transport

Finally, classifications may be made, from the operational point of view - linked with the achievement form - among those to be found in the Field (such as type of riverbed or entrance visibility) and those possibly obtained in the Office (such as basin area or constant maximum load design).

The group of ***inventory variables*** adopted is not closed, that is, with the passage of time and experience acquired in the use of the system, it is possible to add, remove or replace variables.

It is also important to point out that it is not necessary to complete values of all variables of a bridge to be included in the Management System process, not even for the worsening of qualifications due to lack of information. Naturally, there are inventory data, which are indispensable and should be present in order to constitute certain records in the database (such as road and name of bridge or its location along the road).

The system may operate correctly with "thin" data, without this being translated into inadequate qualification of a work possessing few data. This is so, because operations towards priority indicator definition are not additive.

The system logic has been developed precisely in this way as it is considered that many data permitting better evaluation of certain aspects are not currently available.

5.3 Evaluation Module

The Evaluation Module is the one permitting the incorporation of all field and office information, which determines the condition state of each element at the moment of inspection.

In order to carry a general qualification of each structure and to assign a Priority Index to each of them according to the description presented further on in the Priority -setting Module, a ser ies of Evaluation Variables have been selected.

Evaluation Variables are shown next in a hierarchical tree with several levels (Table 1), its branches growing from general (left) to particular and more detailed aspects (right). Evaluation Variables are co lored grey in Table 1, in which it may be seen that, according to variable type considered, the level of detail for making the evaluation differs. The depth level adopted for evaluation is directly related to quality of the results expected with relation t o the precision of priority forecasts, the latter to the corps of experts carrying out the evaluations.

In this first stage of system implementation, it has been opted to limit depth and detail of evaluations at levels 3 and 4, as per type of variable and in accordance with that indicated in Table 1.

It is important to point out that the system permits incrementation in the future, either by adding levels or increasing amounts of variables considered at each level. Naturally, this implies an increment in capacity, specialization and training of inspectors making the evaluations. In turn, algorithms must be adjusted and fed again, being this an advantage feature of the logic being used, which allows to work today with an incomplete database and to add more detailed levels later on.

Every Evaluation Variable appearing in the grey rectangles of Table 1 has been submitted to qualification by inspectors responsible for the evaluations. The qualification is of literary type in order to be able to handle values with the lack of precision involved in these evaluations (see Figure 2). The general criteria for assigning these values derive from actions considered by evaluators should be adopted as a function of the condition state of the element evaluated. The assignment of literary values indicated in Figure 2 to qualifications of each element is simple for an expert in the subject corresponding to the variable being evaluated.

This system is prepared in such a way that, at entering a qualification implying damage s, functional obsolescence or operational deficiencies, the expert is requested to include ***type and extension of damage*** observed.

In accordance with experience acquired from observations of network bridges coming under this system, data habitually found a s corresponding to each **evaluation variable** have been typed. Table 2, for instance, gives a partial list of ***damage types*** included in the current system version. Upon indicating some of these data, the system was supplied with a damage extension measurement. This information has dual value: on the one hand it permits identification of action to be taken or repair to be made when the moment arrives for acting on each work and, on the other, costs may be estimated at planning level for different activities to be carried out.

Relative to extension, each damage or problem indicated in Table 2 may be classified, at first instance, as a local or general extension. For example, certain variables are quoted and the significance of this extensionis as follows : Qua lified as local would be an isolated fissure in a beam, scour in a pillar or corrosion in a specific place in reinforcement bars. For these same damages, extension would be qualified as general when a beam is totally fissured, when there is general scour or a reinforcement corrosion problem present in many sectors of one piece.

Among these possibilities of local or general damage, it should be indicated if the damage has been detected in one element, various elements or all elements.

5.4 Costs Module

This module determines rehabilitation costs of bridges on the basis of type and extension of damages detected and qualified during evaluations.

The objective is not to have precise knowledge of rehabilitations costs for a particular work but rather to use t his information for planning purposes. Given the depth and detail of evaluation inspections done in this case, it was only possible to make evaluations of estimated costs with the aim of reaching global amounts for groups of works or determined time period s.

In order to calculate rehabilitation cost, an algorithm has been implemented, based on different elements and operating on the data base. For Routine Maintenance and Routine Inspection costs, mean representative values have been adopted per bridge sur face unit, this being considered adequate for planning purposes.

5.5 Priority-Setting Module

This module includes all system operations to be carried out for helping the planner make decisions. The final objective of this priority -setting algorithm is to establish an order of priorities for assigning funds, as per results obtained for evaluation values and considering interrelations diagrammed and explained in Table 3.

5.6 Reports Module

This System module permits obtaining information referred to the b ridge network and its status at a determined moment. There are basically two great types of reports:

Reports referred to Inventory Data

It is possible to create reports on the physical configuration of network bridges, as per the way they were inventorie d. Through a system of filtering information of all inventory variables contained in a data base, it is possible obtain, from all data on a determined bridge to statistical type information, such as lists of bridges with determined structure types located on a determined road route.

Reports related to Bridge Status

In this case as well, users have access to screens with guidance through different filters in order to obtain information on status of all elements evaluated in a determined bridge, or for example, issues of lists of all bridges in a state of emergency due to hydraulic aspects.

5.7 Planning Module

This module issues data useful to the planner, such as ordering of all bridges as per their Priority Index and the estimated cost of investments required by each one.

It is possible to create Maintenance and Rehabilitation plans for annual or six-monthly periods and a determined investment amount, respecting orders of priority, or to alter said orders externally and obtain investments necessary for attending to determined works indicated by the planner.

6.0 CONCLUSIONS

It may be seen that the Bridge Management System implemented is a powerful tool for carrying out economic planning tasks , based on the physical reality of bridge networks. Apart from economic planning, a great amount of technical information is provided for carrying out maintenance and rehabilitation of every bridge.

It is evident that results derived from system operation mainly depend on quality and depth of evaluation inspections and the careful entry of data. It is extremely important , therefore, during use, that the data base be kept up-to-date and that evaluations made in the first stage for start-up purposes, be adjusted accordingly.

Inclusively, as said several times, the system is prepared for extension of its information base and to go into depth in the technical details of evaluations. In this respect, there should be people expert in different field involved and additional efforts made in programming to add greater levels of detail. Nevertheless, It is considered that improvements of this nature may only be applied after a certain period of intensive use of this System by the corresponding entity, only after having acquired specific experience in their application to the bridge network in question.

The use of a filmed inventory allows revising over and over the inputted information in the BMS, without the need to visit the bridge site. Also, the filmed data permits for the historical storage of the physical visual condition of the structures and their environment.

The incorporation of the BMS into the roads' network GIS allows to have an overall visualization of the infrastructure system, making decision taking easier in case of emergency at the event of roads or bridges collapses

7. ACKNOLEDGMENTS

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Table 1

HEIRARCHICAL TREE OF EVALUATION VARIABLES

NIVEL 1	NIVEL 2	NIVEL 3	NIVEL 4	
IP PRIORITY INDEX	PFE Propensity to Structural Failure	SU Superstructure		Principal Elements
				Secondary Elements
				Tertiary Elements
				4^{th} Level Elements
				Deck or Slab
				Rolling Surface
				Traffic Barriers
				Railings
				Curbs or Pavements
				Joins
				Drains
				Signs
		IN Infrastructure	Supports	Support Apparatus
				Support Blocks
			Piles	Support Beams
				Antiseismic Blocks
				Columns
				Intermediate Cross Beams
				Walls
				Diagonal Bracing
			Abutments	Upper Wall
				Support Beam
				Antiseismic Blocks
				Inferior Wall
				Columns
				Lateral Walls
				Buttress
				Abutment Wing
			Foundations	Displaced Footing
				Isolated Footing
				Tie Beam
				Pile Head(er)
				Apron
		AC Approaches		Front Surfacing
				Cone Room Surfacing
				Lateral Surfacing
				Revetment Foundation Wall
				Access Slab
				Access Drains
				Barriers
				Bumpers
				Embankments
				Traffic Signs
				Pavement Painting
	VAE Vulnerability to External Agents	HY Hydraulics		General Undercutting
				Localized Undercutting
				Aggression to Abutments
				Degradation of River Bed
				Aggradation of RiverBed
		RO Real Overloads		
		EN Environment		Aggressive Fumes or Gases
				Aggressive Liquids
				Sulphated or Chloride Water
				Sulphated or Chloride Soil
	FO Functional Obsolescence	RW Road Width		
		VC Vertical Clearance		
		DL Design Load		
		UL Useful Life		
	SOI Strategic and Operational Importance	FI Functional Importance		Strategic Importance (military)
				Civil Use Importance (Economic)
				Touristic Importance
				Politic Importance
		EC Emergency Cost		Repair Costs
				Costs of Emergency Repairs in event of bridge collapse
				Cost of Operating Vehicles along Alternative Routes
				Costs of Temporary Weight Limitation
				Additional Cost due to Road Section Reduction

Table 2

Most Frequent Damages

BARRIERS	*Absent*
	Impacted
	Destroyed
	Deficient Anchoring
	Deformed
	Corroded
	Missing Elements
	Inefficient
BUMPERS	*Absent*
	Impacted
	Destroyed
	Deformed
	Inefficient
EMBANKMENTS	*Settled*
	Displaced
	Deformed
TRAFFIC SIGNS	*Absent*
	Paint Worn Off
	Destroyed
	Crashed
	Hidden
	Illegible
	Confusing
PAVEMENT PAINTING	*Absent*
	Paint Worn Off
	Hidden
	Illegible
	Confusing
GENERAL SCOUR	*Deep*
	Extended to sides
LOCALIZED SCOUR	Deep
	Affecting firm soil
AGGRESSION TO ABUTMENTS	*Permanent*
	Growing
	Outer side of curve
	Inner side of curve
	Straight riverbed

DEGRADATION OF BED	*Deep*
	Extended to sides
AGGRADATION OF BED	*With gravel*
	With small cobbles
	With fine soil
	With vegetation
REAL OVERLOADS	*Very heavy and frequent*
	Occasionally very heavy
	Over design loads
AGGRESSIVE FUMES OR GASES	*Aggressive to concrete*
	Aggressive to steel
AGGRESSIVE LIQUIDS	*Aggressive to concrete*
	Aggressive to steel
WATERS WITH SULPHATES OR CHLORIDES	*Content over limits*
	Verified aggressiveness
	Assumed aggressiveness
SOILS WITH SULPHATES OR CHLORIDES	*Content over limits*
	Verified aggressiveness
	Assumed aggressiveness
ROAD WIDTH	*Inadequate for two lanes*
	Inadequate for one lane
	Inadequate for heavy traffic
VERTICAL CLEARANCE	*Insufficient*
	Not uniform
DESIGN LOAD	*HS-15*
	Unknown
USEFUL LIFE	*Very advanced deterioration*
	Advanced deterioration
	Urgently requires maintenance
	Inadequate structural safety
STRATEGIC IMPORTANCE (military)	*Vital communication medium*
	Zone included in special plans
IMPORTANCE FOR CIVIL USE (Reg. Econ.)	*Only access to settlement*
	Economical development plan zone
TOURISTIC IMPORTANCE	*Important touristic corridor*
	Archeological deposits
	Picturesque road

Table 3

SCHEME FOR IMPORTANCES AND INFLUENCES AMONG VARIABLES

IMPORTANCE OF VARIABLES OF ONE LEVEL FOR DETERMINING VALUE OF UPPER LEVEL	Examples:
	Importance held by railing in superstructure qualification.
	Importance of localized scour for qualification of vulnerability to external agents.
	Importance of road width for qualification of functional obsolescence.
	Importance of costs of emergency for qualification of operational importance of work
INFLUENCE AMONG VARIABLES OF SAME LEVEL AND INFLUENCE BETWEEN EVALUATION VARIABLES OF ONE LEVEL AND SOME INVENTORY VARIABLES	Examples:
	Influence of foundation type when qualifying scour: e.g. scour is noted as generalized, notable or advanced in a bridge. This data loses importance if later in the office it is confirmed that the foundation has piles.
	Influence of AADT on road width qualification. For example, its importance would be diminished by the algorithm if the bridge is found to have a low AADT.
	Influence of emergency cost on operational importance. A bridge on a main route is analyzed without alternatives in case of collapse and without the possibility of constructing an emergency bridge. The work importance is magnified by the fact of a possible emergency being very costly.
TRIGGER CLAUSE FOR EMERGENCIES	It has been considered that, in spite of an algorithm operating with non additive variables - this implying that the state of many variables does not invalidate the influence of the few badly qualified – it has also been established that there are certain variables which should trigger an emergency in the event of detecting the existence of an emergency key element. For example, if a local crack is found in one main beam of bridge but is qualified as VERY BAD since it is considered an emergency, the algorithm is able to qualify the whole bridge in a state of emergency even though remaining elements are in perfect condition. This clause, known as a "trigger", is associated by the algorithm with evaluation variables considered as critical relative to experience.
ACTIONS TO BE CARRIED OUT ON THE BASIS OF EVALUATIONS	For example, let's assume that the railing is destroyed and qualified as VERY BAD. The result of this evaluation is that this railing is in a state of emergency but the superstructure may not be so if its main elements are in good shape. By the same token, operational importance may be tiny if there is a simple alternative when a bridge collapses and, for example, a parallel road is available.