Proposal of Maintenance Management Database for Highway Bridges in Vietnam

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The deterioration of highway bridges in Vietnam becomes a major social and technical concern. Furthermore, current maintenance management system is considered outdated so does not satisfy local traffic demand. In order to overcome this problem, the paper attempts to develop a practical maintenance management system (V-BMS) concurrently with a computerized database for highway bridges in Vietnam. The status of existing bridges is to review to identify outstanding shortcomings. Next, several assessment techniques are introduced to evaluate current status and future trends of highway bridges in most suitable manners. Continuously, practical application of the proposed V-BMS is presented to demonstrate and verify the validity of the proposed system.

Key Words: Bridges, Highway, Maintenance, Management, Vietnam

1. Introduction

Recently, emphasis has been very much placed on new constructions of bridges. The importance of maintenance is normally emphasized in about 10 years after construction, but not throughout entire lifespan of in-service bridges. Inappropriate maintenance and management often cause existing bridges to be degraded by lack of durability, integrity and serviceability. These not only happen worldwide, but are very common and serious at poor countries where annual maintenance budget is considerably very low comparing with new construction costs and total bridge values. Present practice moreover prioritizes scared resources on either actual site maintenance or in-house management, while assessment aspect has not highlighted to reflect its important roles. As the result, existing bridges are generally in poor physical quality and functionality to be unable serving for traffic and social demands and prevent development of the economy.

Highway network in Vietnam stretches for 15,360 km throughout entire country to consist of 4,107 bridges with total length of 150,374 m contributing significantly for social and economical development (TMoVN[1]). According to Hai et al.[2], even existing bridges in Vietnam are in poor physical condition with many defects such as corrosion, fatigue and aging, there is currently a lack of proper maintenance management system. This put Vietnamese bridges at no-attention prospect against adverse impacts of external climate, over-traffic, financial shortage, etc. In order to overcome this problem, the paper therefore proposes a model to appropriate with maintenance management practice of existing bridges in Vietnam. The objective is to manage Vietnamese bridges in suitable manner, to utilize efficiently scared budgets and to orient maintenance management activities on most necessary requirements. Furthermore, a computerized database system is established to demonstrate as an example of the proposed model on local condition of Vietnam, to verify its validity and to recommend modification if there is any.

2. Present Condition of Highway Bridges in Vietnam

2.1 Physical Condition

Existing highway bridges in Vietnam are classified by the transport ministry of Vietnam in terms of lengths, construction time, deck widths and load-carrying capacities (TMoVN[1]). The statistical data shown in Fig.1a confirms that bridges are mostly in the small and medium size categories, accounting for 65.72% and 22.55% of the total respectively. Many weak/very weak and narrow/very narrow bridges are still in service although they can definitely not satisfy the requirement of modern vehicles where there is demand for 25 ton and 14m width normally. Fig.1b shows 28.59% and 18.36% bridges are in the 10 ton and 13 ton load-carrying capacities respectively. Meanwhile, 31.82% and 45.22% of bridges have traffic lanes less than 6.5m or from 6.5 to 10m width (Fig.1c). Bridge' ages are in the medium range of 10 to 50 years with 52.97% built in period of 1975-1995 and 33.19% bridges built between 1954 and 1975 (Fig.1d).

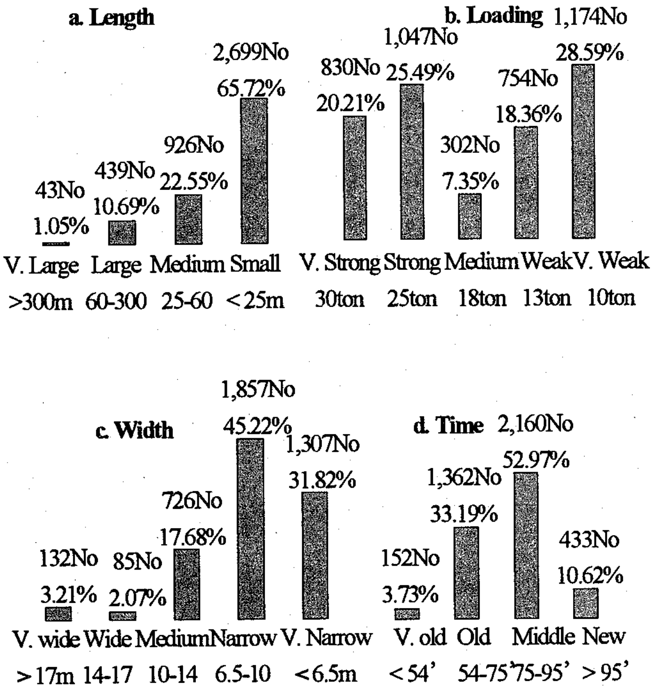

Fig.1. Classification of existing highway bridges in Vietnam

Existing bridges in Vietnam are generally in poor physical condition and serviceability with several outstanding problems that are from not only the bridge structures themselves, but also from other aspects of current traffic, the society, highway routes, etc. According to Hai et al. [3], several common types of failure modes, sorted in order of seriousness and frequency, are as: corrosion, fatigue damage, functional obsolescence, aging, human invasion, construction defect, missing element, scouring, and others. Moreover, Vietnamese bridges have a wide range of shapes, commissioning dates, and have been built by various different design standards (Hai [2]). Some have been subjected to the impact of wars, the adverse climate, and poor maintenance management. Meanwhile, there are differences occurring from geographical locations due to scattering through mountains, deltas and coasts; and the climate as the northern area has four seasons (spring, summer, autumn and winter) and the southern area only has rainy and dry seasons (TMoVN [4]). An extreme increase in vehicles carried in terms of volumes and weights is moreover adversely impacting the current condition of bridges. There is an assumption that bridges built after 1995 in Vietnam can satisfy current traffic demands as increased safety factors have been used in design stages. However, it seems that many bridges built before 1995 are not adequate for current transported loads and jams, especially those which were affected by wars.

2.2. Maintenance Management Practice

(1) The Bridge Owner and Agencies

According to definition of Barrie and Paulson [5], bridge owner and its agencies in Vietnam are currently organized in top-down functional structure (Fig.2). The owner is the government of Vietnam who provides financial and other supports to design, construct, operate and maintain for all existing bridges. Meanwhile, maintenance management agencies act as subsidiaries of the government of Vietnam. If direct agencies are considered necessary for site maintenance management, indirect ones act only as the intermediation to connect between the owner and direct agencies. Their correspondences and activities flow vertically in directions of top-down or bottom-up. Horizontal interlinked relationships among these agencies are not applying in Vietnam as currently there is not much coordination and information shearing among them. Several advantages of the functional organization have found in Vietnam for high stability, stable professional, excellent corporate memory, and so on.

(2) Bridge Management

According to Hai [2], highway bridges in Vietnam are managed by management and repair companies with duties: administrate bridge-related data, inspect and evaluate physical and serviceable conditions, and ensure the safety and smooth operations. Thus, these companies attempt to manage bridges in three aspects.

1. Inventory-data: all data has currently being managed in manual manner by unprofessional staff. The data is therefore not properly sorted and edited while computerized database system is not yet available in Vietnam.
2. Physical site: existing bridges are frequently invaded by unexpected aliens (people, animals, vegetations, etc) that create adverse impacts. However, several important ones are guarded by in-house staff of the management and repair companies.
3. Inspection: bridges are regularly and periodically inspected. Furthermore, they are under special evaluation in periods of 3-5 years. Bridge physical condition is to rate according to Table 1.

Table 1. Physical rating for highway bridges in Vietnam

Level	Descriptions	Maintenance
0	There is no or minor defects only, those not impact on structural safety and serviceability of bridges	Not required
I	There are minor failures and defects, but not weaken on structural safety and serviceability of bridges	Regular maintenance is required
II	There are defects those currently develop and impact on structural safety and serviceability of bridges	Periodic maintenance is required
III	There are serious defects those adversely impact on structural safety and serviceability of bridges	Special maintenance is required

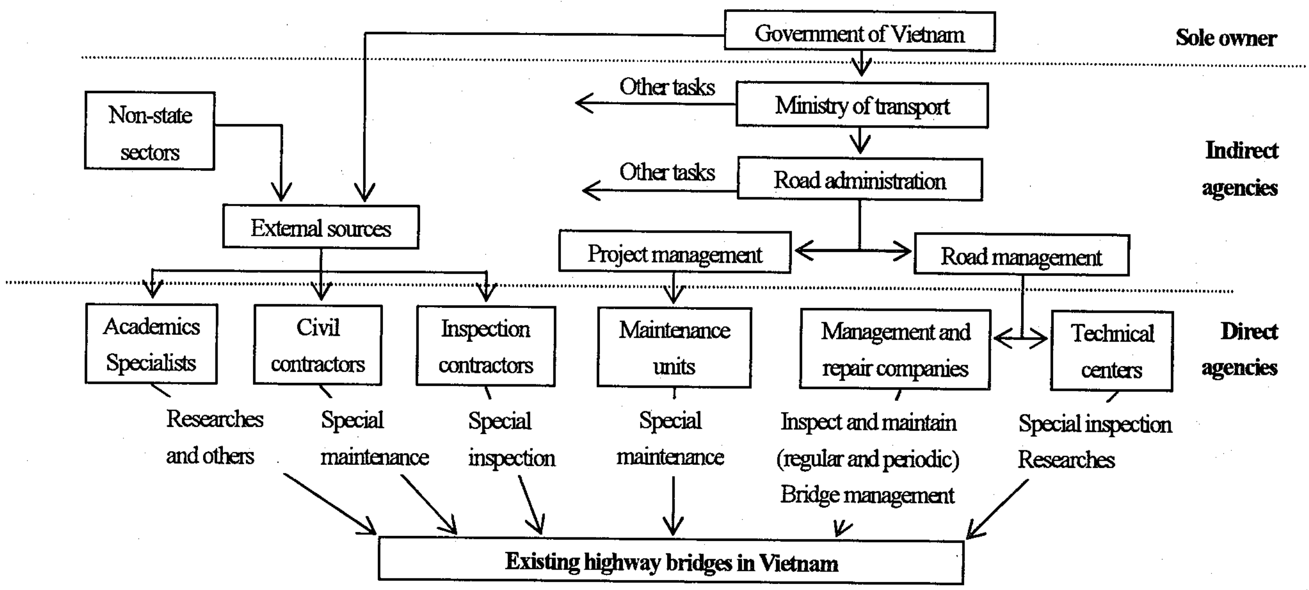

Fig.2. Current organizational structure of bridge owner and its agencies in Vietnam

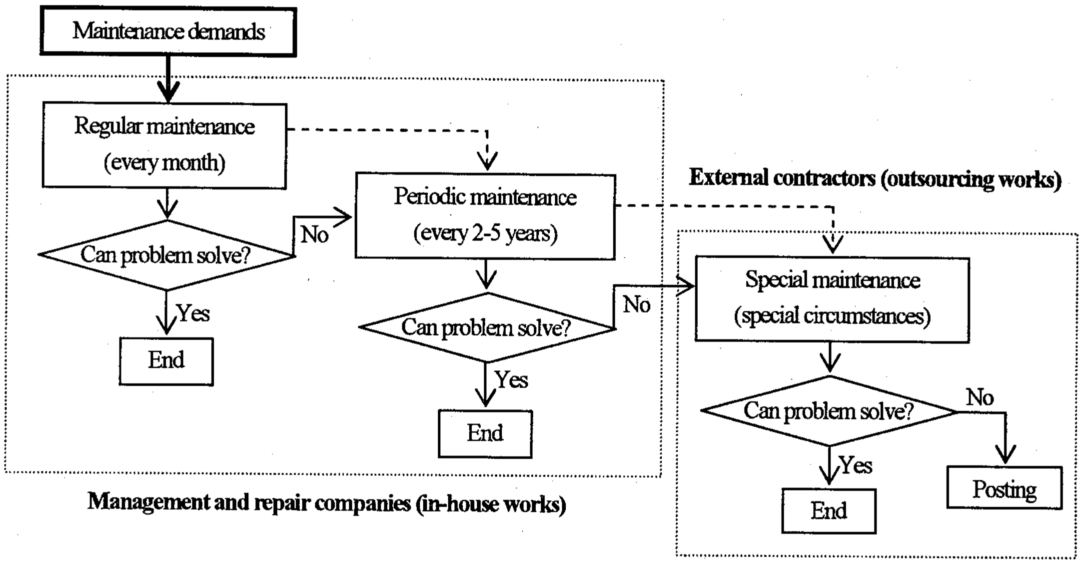

Fig. 3. Categories of site maintenance for highway bridges in Vietnam

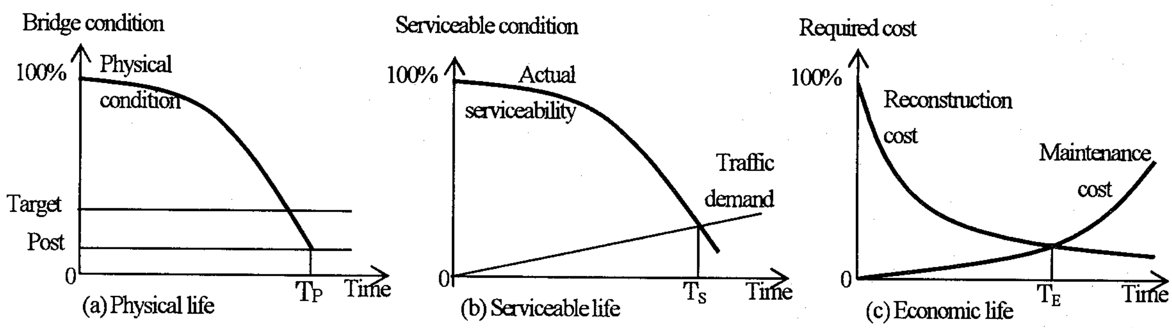

Fig.4. Lifespan estimation for highway bridges

(3) Bridge maintenance

Site works are carried out to ensure safety of road users and smooth of traffic on highway bridges in Vietnam and to maintain their structures at reasonable quality against impacts of overloads, the climate and human invasions (Hai [2]). In addition, the owner wishes to preserve structural and serviceable capacity as long as possible to reduce the life cycle cost while bridge lifespan can extend. However, these are not much emphasized in the practice due to lack of finance and attention to maintain properly existing bridges. Current regulation in Vietnam (TMoVN [4]) regulates site maintenance into three categories as shown in Fig.3.

2.3. Outstanding Problems of Bridges in Vietnam

The overview of the physical condition and the maintenance management practice unveil several outstanding problems currently occurring on highway bridges in Vietnam as below.

1. Highway bridges are generally in poor physical and serviceable condition with many failure modes that currently occur such as corrosion, fatigue damage, obsolescence, aging, human invasion, construction defect and missing element.
2. There are many unsynchronized bridges closely located along the same tracks whose load-carrying capacity and deck width are very much different. Moreover, bridges and roads are not homogeneous as many bridges are classified in weak and narrow categories against strong and wide roads.
3. Annual budget provided can satisfy about 30-50% actual demands only. This means approved budget for next fiscal year from bridge owner only can cover 30-50% of actual submitted budget of direct maintenance agencies. Therefore, required maintenance management for existing highway bridges in Vietnam are impossible to be efficiently carried out on time and had to either cancelled or postponed.
4. There is a long distance with many hierarchies from bridge owner and direct agencies. This creates bureaucracy, communication slowdown, cost acceleration, and so on.
5. Good management system encompassed computerized database has not yet applied. Therefore, bridge inventory data is not properly managed, but in intuitive and manual manner. In addition, priority criterion that is to assess required demand and to prioritize budget on necessary works has not yet applied.

3. Assessment for Physical Condition of Existing Bridges

3.1. Lifespan Estimation

Expected lifespan of existing bridges should be approximately estimated to make right maintenance decisions in economically safe manners. However, different factors influence on bridge structures to make difficulties in accurately deciding actual lifespan. Yatomi et al. [6] considers bridge lifespan depends not only on engineering assessment for physical condition, but on social and economical aspects as well as different views reflect different lifespan. The paper therefore estimates entire lifespan of bridges in three aspects (Fig.4). Though initial designs try making T_P, T_S and T_E as close as possible, bridges however unlikely have one approximating the others due to unforeseeable climate, traffic, price fluctuation, etc. Thus, the estimation should be carried out to evaluate actual deterioration and to decide ideal lifespan.

1. Physical life (T_P): due to damages, bridge performance at time T_P decreases and becomes unable to withstand traffic uses.
2. Serviceable life (T_S): the function required changes due to the change in social requirement, the expected function can be no more realized at the time T_S.
3. Economical life (T_E): in cost consideration required to prevent the bridge from deterioration, it decides at the time T_E as posting and reconstructing option is more economic than continued maintenance and the use of bridge.

3.2. Deterioration Prediction

Deterioration prediction for physical condition and load-carrying capacity should be carried out with assistance of computer simulation to identify current bridge status. Physical condition encompasses *durability* as ability to resist deterioration and *surface appearance* which is defined from total damage, execution of works and serviceability. Meanwhile, load-carrying capacity can be considered as ability of the bridge to withstand imposed loads of traffic, self-weights, winds, and so on. They are drawn as integrated convex curves (Eq (1) and (2)) because deterioration processes rapidly with its age. Vertical axes represent the value of load capacity (*LC*) and the percentage remaining of physical condition (*PC*), while horizontal axes are for bridge age (Fig.5). R_{PC} and R_{LC} ($\geq$1) are experimental constants and t is the bridge age. $PC_{100\%}$ and $LC_{100\%}$ are values when newly-built bridge enters service. On the other hand, these values respectively are $PC_{Posting}$ and $LC_{Posting}$ for the bridge when being posted and removed from service. T_{PC} and T_{LC} are the time when bridge is required to be posted as its current physical condition (PC) and load capacity (LC) reach its posting levels.

$$PC = PC(t) = (PC_{100\%} - PC_{Posting})[1-(\frac{t}{T_{PC}})^{R_{PC}}] + PC_{Posting} \quad (1)$$

$$LC = LC(t) = (LC_{100\%} - LC_{Posting})[1-(\frac{t}{T_{LC}})^{R_{LC}}] + LC_{Posting} \quad (2)$$

3.3. Life Cycle Cost (LCC) Analysis

Total costs associated over entire lifespan that need to construct, maintain and manage a bridge since its initiation until posting time, should be carefully analyzed. Since the *LCC* reflects economical aspect of bridges, it is an important criterion to decide necessary works. However, there is neither *LCC* concept nor its estimation applying in Vietnam now. This part therefore analyzes the *LCC* and proposes a methodology to ensure adequate level of lifetime reliability at lowest possible cost. The *LCC*, according to Fragopol [7] can be expressed in Eq.(3). $C_{initial}$ is the initial costs need to cover expenses associated with feasible studies, design, construction, etc. Meanwhile, management fee symbolized as $C_{management}$ is the budget allocated for bridge management. Maintenance cost ($C_{maintenance}$) is paid for site works to either remedy current damages or prevent their occurrences. This paper assumes the $C_{management}$ constantly throughout entire lifespan to pay for in-house management activities on existing bridges. The $C_{initial}$ meanwhile is generated prior the year 0 where construction works of newly-built bridges are completed. However, $C_{maintenance}$ that is emphasized in the research is changeable value to depend on actual site maintenance and its specific time. It makes remarkable differences in LCC and lifespan of existing bridges if differences of maintenance options are selected.

$$LCC = C_{initial} + C_{management} + C_{maintenance} \quad (3)$$

In practice, there are various options of site maintenance applied for existing bridges. This paper however emphasizes on only three options of changeable $C_{maintenance}$ to analyze their differences in LCC and lifespan (Fig 6). Option ① does not require any maintenance throughout entire bridge lifespan ($C_{maintenance}$ = 0). The physical condition and the load-carrying capacity therefore degrade freely from 100% to posting level. In this option, while LCC1 is minimized for only $C_{initial} + C_{management}$, lifespan T1 is however in the shortest time. If essential maintenance is carried out at time t2 according to option ② in order to pick up vertically bridge quality, $C_{maintenance}$ generated increases total costs to LCC2 and to extend lifetime to T2. Simultaneously, option ③ considers an early preventive maintenance at time t3 even an existing bridge is still in reasonable physical condition and serviceability. Total costs increase up to LCC3 while the bridge can last until time T3. Depending on specific maintenance situation, the most suitable option is selected to enable bridge owner and maintenance agencies financing for required costs and ensuring the physical condition and the load-carrying capacity certainly above the targeting level.

3.4. Priority Maintenance under Budget Constraints

Currently, bridges in Vietnam are in poor quality status to require huge maintenance costs. However, allocated budget limits only 30-50% actual requirement (Hai [2]) to force the owner eliminating certain works. The approval of maintenance does not depend on bridges only, but also on other factors such as budget availability, social preference and personality. The priority for repairing is not specified at present to equally consider bridges those differ in location, damage, circumstance, etc. This paper therefore proposes priority maintenance index (*PMI*) calculated by Eq.(4), a technique for determining socially preferential maintenance according to bridges' location and their physical quality. The owner can select certain bridges with highest *PMI* to fit in its limited budget while low the rest can postpone for next fiscal years. *BI* and *BH* are important and health indexes respectively. The α_1 and α_2 are important and health factors with total value $(\alpha_1 + \alpha_2) = 1$. As an example for specific condition of Vietnam, this paper assumes $\alpha_1 = 0.4$ and $\alpha_2 = 0.6$.

$$PMI = \alpha_1 BI + \alpha_2 BH \quad (4)$$

(1) Bridge Important Index (*BI*)

The *BI* evaluates important degree of existing bridges in terms of location, serviceability and traffic demand. It has maximum value up to 100 in accordance with Eq.(5) as I_L, I_W and I_T are practical indexes of location, width and traffic volume (Table 2).

$$BI = I_L + I_W + I_T \quad (5)$$

Table 2. Location, width and traffic volume indexes

Groups	Options	Values
Bridge location	Urban bridges	$I_L = 40$ #
	National highway bridges	$I_L = 35$ #
	Provincial road bridges	$I_L = 25$ #
	District road bridges	$I_L = 15$ #
	Commune road bridges	$I_L = 5$ #
Bridge width	Very wide (over 17m)	$I_W = 20$ #
	Wide (14-17m)	$I_W = 15$ #
	Medium (10-14m)	$I_W = 10$ #
	Narrow (6.5-10m)	$I_W = 6$ #
	Very narrow (<6.5m)	$I_W = 3$ #
Traffic volume	Extremely high, many jams	$I_T = 40$ #
	High with few jams	$I_T = 35$ #
	Moderate with or without jams	$I_T = 25$ #
	Low without jams	$I_T = 15$ #
	Very low without jams	$I_T = 5$ #

(2) Bridge Health Index (*BH*)

The *BH* is an index reflecting current physical and serviceable status of bridges. Its value is up to 100 and calculated by Eq.(6).

$$BH = SF + SV + TP \quad (6)$$

1. The *SF* is safe degree of bridge structures with maximum value of 50 (Eq. (6.1)). Value of a_i (safe constant of component *i*) correlate with the physical condition (level 0: $a_i = 0.25$, I: $a_i = 0.5$, II: $a_i = 0.75$ and III: $a_i = 1$). The s_i is safe coefficient of component *i* with practical values shown in Table 3.

$$SF = \sum_i a_i s_i \quad (6.1)$$

Table 3. Values of safe coefficient s_i for specific components

No	Components	s_i	No	Components	s_i
1	Foundations	7#	8	Joints	2#
2	Substructures	7#	9	Painting systems	2#
3	Superstructures	7#	10	Safe facilities	2#
4	Upper structures	6#	11	Bearings	2#
5	Auxiliary facilities	2#	12	Drainage system	2#
6	Approach roads	4#	13	Waterproofing	1#
7	Pavements	5#	14	Others	1#

2. The *SV* is bridge serviceability with maximum value of 40 and calculated by Eq.(6.2). b_i and sv_i are serviceable constant and coefficient of criteria i (Table 4).

$$SV = \sum_i b_i sv_i \quad (6.2)$$

Table 4. Values of constant b_i and coefficient sv_i

Criteria	sv_i	Classifications	b_i
Deck widths	10	Very wide (over 17m)	1
		Wide (14-17m)	0.8
		Medium (10-14m)	0.6
		Narrow (6.5-10m)	0.4
		Very narrow (less 6.5m)	0.2
Load carrying capacities	10	Very strong (30ton)	1
		Strong (25)	0.8
		Medium (18)	0.6
		Low (13)	0.4
		Very low (10)	0.2
Deck surfaces	10	Level III	1
		Level II	0.75
		Level I	0.5
		Level 0	0.25
Approach roads	5	Deck is poorer than road	1
		Bridge deck fit in approach road	0.6
		Bridge deck is better than road	0.2
Others	5	Poor serviceability	1
		Moderate serviceability	0.6
		Good serviceability	0.2

3. The *TP* that is impacts of bridges to third parties has maximum value of 10 and is calculated by Eq.(6.3). c_i and tp_i are third party constant and coefficient i (Table 5).

$$TP = \sum_i c_i tp_i \quad (6.3)$$

Table 5. Values of third party constant c_i and coefficient tp_i

Criteria	tp_i	Classifications	c_i
Clearance space	5	Frequently prevent vessels under-crossing	1
		Sometimes prevent vessels under-crossing	0.6
		Not prevent vessels under-crossing	0.2
Bridge location	3	Urban areas	1
		National highways	0.8
		Provincial roads	0.6
		District roads	0.4
		Commune roads	0.2
Physical condition	1	Level III	1
		Level II	0.75
		Level I	0.50
		Level 0	0.25
Others	1	High impact to third party	1
		Moderate impact to third party	0.6
		Low impact to third party	0.2

4. Practical Demonstration of the Proposed System

As outstanding problems have been identified, they must be soon eliminated in order to minimize their adverse impacts on structures and users of bridges. The research therefore proposes an intelligent computerized database and names it as bridge management system of Vietnam (V-BMS). Functions of the proposed system are: to manage bridge-related data, to assess physical condition and functionality of existing bridges, and to decide optimal maintenance management. If the proposed V-BMS is properly applied, the problem 4 and 5 can be totally eliminated from existing bridges in Vietnam. On the other hand, the problem 1, 2 and 3 are solely responsibility of the government of Vietnam as it only enables adjusting macro strategies and policies in order to eliminate them completely. However if being applied, the proposed V-BMS is expected to minimize adverse impacts of these problems by orienting limited budget in most necessary maintenance management.

The proposed V-BMS is constructed on personal computers using the MS Access and Excel languages. In the present study, it is specifically applied in the management and repair company X as a demonstrated example for the validity of the system. Currently, the company manages and maintains for 29 existing highway bridges on 150km national highway segment of Vietnam (Table 6). The proposed V-BMS encompasses three interlinked modules of management, assessment and maintenance (Fig.7). Bridge-involved data such as physical status, serviceability, maintenance works and external condition is firstly entered into the management module. Duties are imposed for this module as: ① frequently review to understand bridge status and ② edit and update the data if there is any change. Next, the V-BMS estimates criteria of present deterioration, remaining life, total LCC, and priority index by computer simulation and expert opinions allocated inside the assessment module. Then, it can

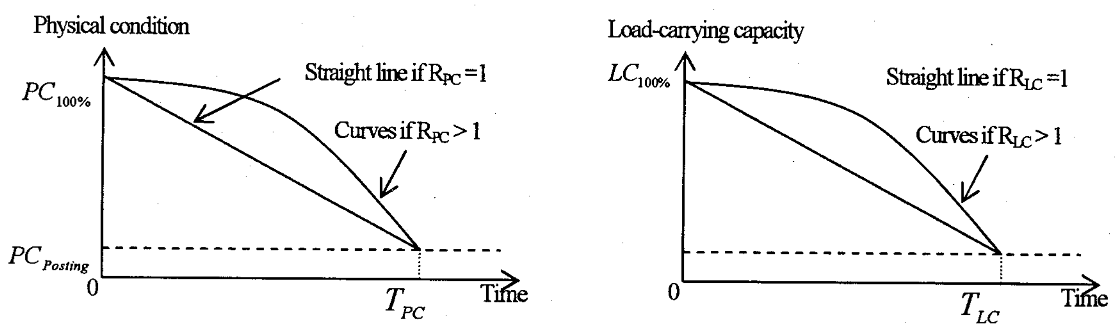

Fig.5. Deterioration curves

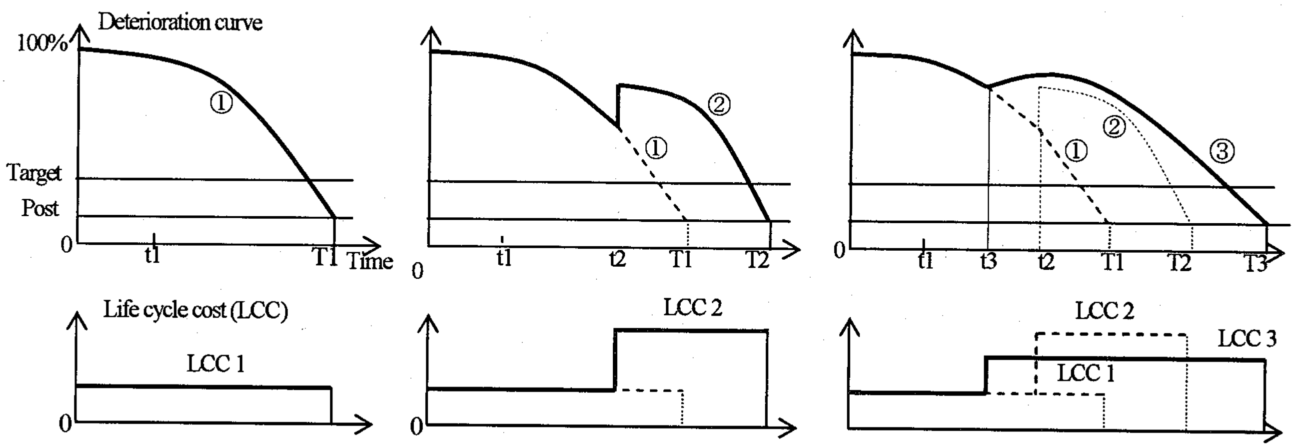

Fig.6. Life cycle cost: ① without maintenance, ② essential maintenance, ③ preventive maintenance

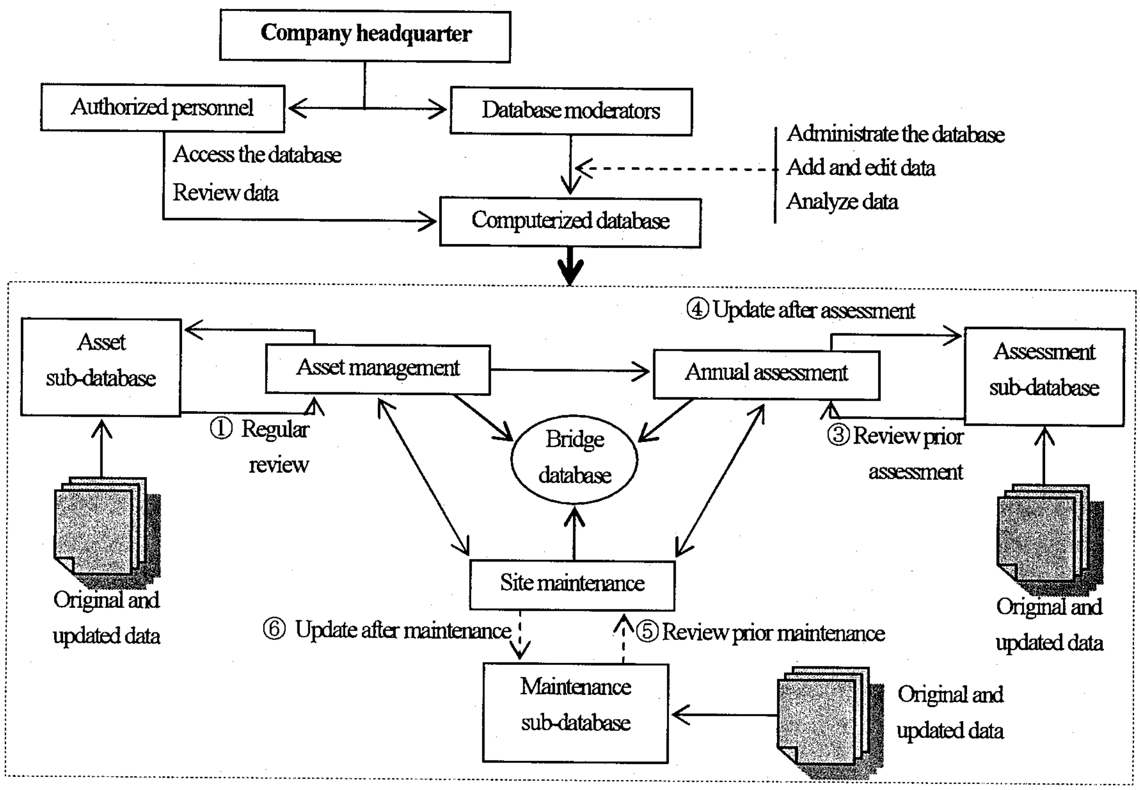

Fig.7. Organizational structure of the proposed V-BMS

finalize scope of maintenance works sorted in priority order that recommend to be carried out. It should be: ③ review prior assessment of bridge condition, and ④ update after any assessment. Finally in maintenance module, authorized people refer to the results of the system assessment to decide actual maintenance management for next fiscal years, basing on budget availability, traffic condition, the society, and so on. This sub-database needs to ⑤ review prior decision of maintenance scope and ⑥ update information after completion of any site work.

Table 6. List of existing highway bridges

No.	Name	Width (m)	Length (m)	Load Capacity	Built (year)
B-1	Bridge 1	37.5	66.8	30 Ton	1998
B-2	Bridge 2	12.1	5.7	30 Ton	1986
B-3	Bridge 3	11.8	170.3	30 Ton	1985
B-4	Bridge 4	12.0	16.7	30 Ton	1976
B-5	Bridge 5	12.0	12.7	30 Ton	1976
B-6	Bridge 6	11.0	68.0	30 Ton	1991
B-7	Bridge 7	12.0	19.1	30 Ton	1976
B-8	Bridge 8	12.0	23.3	30 Ton	1976
B-9	Bridge 9	12.0	20.0	30 Ton	1976
B-10	Bridge 10	12.0	28.1	30 Ton	1976
B-11	Bridge 11	12.0	18.2	30 Ton	1980
B-12	Bridge 12	11.6	59.0	30 Ton	1978
B-13	Bridge 13	12.6	26.3	30 Ton	1977
B-14	Bridge 14	12.6	14.2	30 Ton	1976
B-15	Bridge 15	13.0	23.2	30 Ton	1976
B-16	Bridge 16	12.2	5.7	30 Ton	1977
B-17	Bridge 17	12.0	21.1	30 Ton	1978
B-18	Bridge 18	12.0	27.5	30 Ton	1978
B-19	Bridge 19	12.0	18.5	30 Ton	1978
B-20	Bridge 20	12.0	21.2	30 Ton	1978
B-21	Bridge 21	12.9	26.6	30 Ton	1978
B-22	Bridge 22	16.1	61.6	30 Ton	1994
B-23	Bridge 23	7.9	13.8	25 Ton	1964
B-24	Bridge 24	9.0	47.9	25 Ton	1970
B-25	Bridge 25	9.5	30.0	30 Ton	1995
B-26	Bridge 26	5.5	24.4	25 Ton	1965
B-27	Bridge 27	5.5	24.4	25 Ton	1965
B-28	Bridge 28	9.4	42.2	13 Ton	1967
B-29	Bridge 29	7.6	17.6	13 Ton	1967

4.1. Bridge Management Module

(1) General

The *Bridge Management Sub-database* of the management module (Fig.8) shows general information of bridge codes, names, locations, and structural types to help the V-BMS users quickly allocating a bridge in its population. Furthermore, detail data is stored into low hierarchy levels of *management policies, inventory data, external condition, construction and design documents, historical incidents* and *other information* those are interlinked with the main management screen.

(2) Bridge Inventory Data

In the management module, the *inventory data* is a main section that keeps all inventory information related to bridge components such as bearing, cross sections, joints, painting, spans as well as their physical and serviceable status. Click on the *Inventory Data* box from the management module, output screen shown in Fig.9 appears to provide users all available information. Several important inventory data occurs briefly on the screen. The users can click on buttons located on right side of screen to review furthermore bridge inventory data (Fig.10).

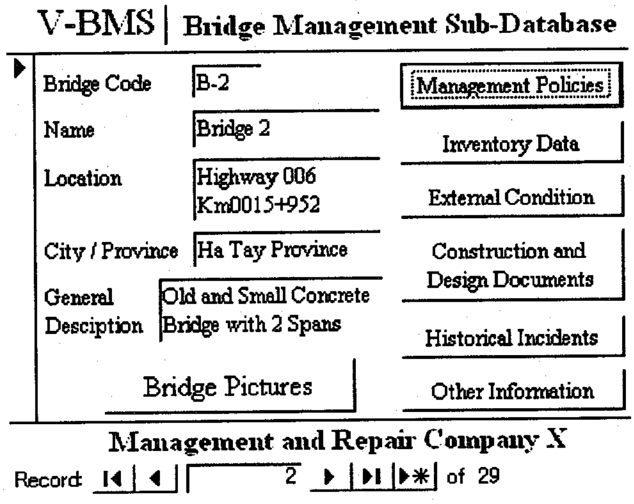

Fig.8. The *Bridge Management Sub-Database*

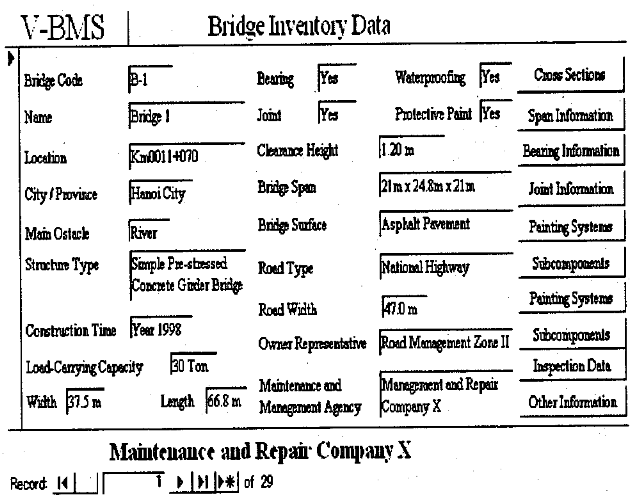

Fig.9. Output screen for the *Bridge Inventory Data*

4.2. Bridge Assessment Module

The *Bridge Assessment Sub-Database* of the assessment module appears as shown in Fig.11. Beside general information of existing bridges, this module also encompasses six sections of assessment policies, lifespan estimation, deterioration prediction, LCC analysis and priority maintenance index. Details of these sections are described as followings.

(1) Lifespan Estimation

As existing bridges are under influences of various external factors, their expected lifespan must be firstly estimated. Options of physical, serviceable and economical lifespan are therefore considered and simulated by the computer to decide approximately the posting time or expected lifespan of bridges. Physical life (T_P): due to damages, bridge performance at the time T_P decreases and becomes unable to withstand traffic uses. Serviceable life (T_S): the function required changes due to the change in social requirement, the expected function can be no more realized at the time T_S. Economical life (T_E): in cost consideration required to prevent the bridge from deterioration, it decides at the time T_E as posting and reconstructing option is more economic than continued maintenance and the use of bridge.

Output screen of the *lifespan estimation* shown in Fig.12 identifies that while physical, serviceable and economical lifespan vary for 84, 82 and 72 years, shortest lifespan of 72 years is selected as expected lifespan. At the time of 72 when economical life is over, the bridge must be posted and replaced as its life is over.

(2) Deterioration Prediction

Basing on the result of the lifespan estimation ($T_{expected}$ or T_E), the deterioration curves of the physical condition and the load-carrying capacity can be plotted on the screen (Fig.13). Expected deterioration is the curve ① with lifespan T_{E1}. However, actual deterioration may differ from the origin ① and change to the curve ② (shorter) or the curve ③ (longer). In practice, site maintenance is definitely carried out to make deterioration of existing bridges changing to the curve ④.

(3) LCC Analysis

Total costs that occur on whole lifespan should be counted in life cycle cost (LCC) of bridges. However, LCC depends much on maintenance activities carried out on the sites and correlates with lifespan of bridges. Even there are many options, the proposed V-BMS calculates and plots for 3 most common LCC that shown in Fig.14 as ① LCC1: no site maintenance, ② LCC2: essential maintenance, and ③ LCC3: preventive maintenance.

(4) Priority Maintenance Index

Upon scope of required maintenance is finalized, the *Priority Maintenance Index* (BPI) should be considered to orient limited fund on necessary works. The *BPI* is built up from two factors: (a) the important index evaluates the importance of bridges in term of their location on highway track and (b) the health index considers current physical condition, load-carrying capacity and surface appearance. The proposed V-BMS calculates the BPI according Eq.(6) and output them in Table 7 concurrently with required maintenance costs estimated by inspectors.

Table 7. Maintenance priority order and estimated costs

Bridge Code	*Bridge Name*	*Priority index (BPI) - Order*	*Maintenance costs (VND)*
B-1	Bridge 1	60.17 # (14)	5,000,000
B-2	Bridge 2	85.21 # (1)	1,300,000
B-3	Bridge 3	65.49 # (10)	16,800,000
B-4	Bridge 4	58.83 # (16)	2,700,000
B-5	Bridge 5	52.16 # (23)	1,600,000
B-6	Bridge 6	72.31 # (5)	6,700,000
B-7	Bridge 7	53.61 # (21)	2,900,000
B-8	Bridge 8	51.28 # (24)	1,800,000
B-9	Bridge 9	55.67 # (17)	500,000
B-10	Bridge 10	75.11 # (4)	2,600,000
B-11	Bridge 11	62.85 # (11)	3,600,000
B-12	Bridge 12	49.86 # (27)	9,000,000
B-13	Bridge 13	50.96 # (26)	1,100,000
B-14	Bridge 14	54.57 # (18)	2,100,000
B-15	Bridge 15	69.25 # (6)	4,700,000
B-16	Bridge 16	53.57 # (20)	900,000
B-17	Bridge 17	58.96 # (15)	2,800,000
B-18	Bridge 18	49.17 # (28)	3,600,000
B-19	Bridge 19	78.63 # (2)	8,700,000
B-20	Bridge 20	60.34 # (13)	1,800,000
B-21	Bridge 21	68.15 # (8)	4,100,000
B-22	Bridge 22	48.72 # (29)	1,300,000
B-23	Bridge 23	76.74 # (3)	5,600,000
B-24	Bridge 24	52.67 # (22)	500,000
B-25	Bridge 25	51.17 # (25)	6,900,000
B-26	Bridge 26	62.58 # (12)	2,300,000
B-27	Bridge 27	68.67 # (7)	1,400,000
B-28	Bridge 28	54.93 # (19)	7,100,000
B-29	Bridge 29	65.81 # (9)	2,700,000
Total required maintenance cost			**112,100,000**

(Note: VND is official currency of Vietnam)

4.3. Bridge Maintenance Module

The *Bridge Maintenance Sub-database* output screen of the maintenance module appears as shown in Fig.15. It includes several important information to recognize an existing bridge as its code, name, location, city (province) and general description. Further maintenance data can be accessed in by clicking boxes of the *Maintenance Policies*, the *Maintenance Records*, the *Maintenance Selection for Next Fiscal Years*, the *Details of Maintenance* and the *Other Information*.

(1) Maintenance Records

The *Maintenance Records* stores all information of past maintenance (e.g. scopes, locations and costs). By supervising maintenance activities on sites, in-house staffs or moderators enable to collect all maintenance data and to input them in the computerized database. Details of site maintenance are briefly shown in Fig.16 while full information can be referred from filed documents kept at headquarters of the management and repair companies.

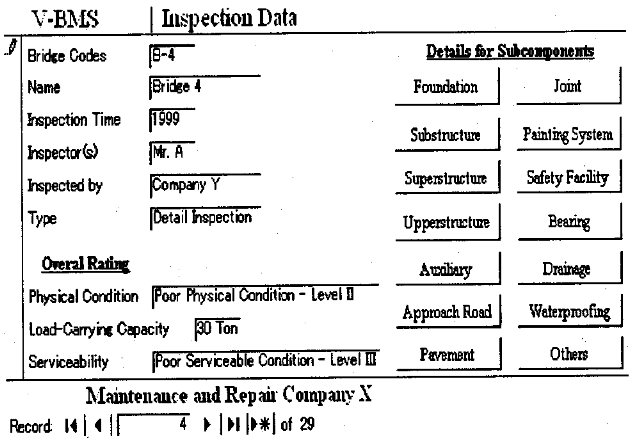

Fig.10. Output screen for the *Inspection Data*

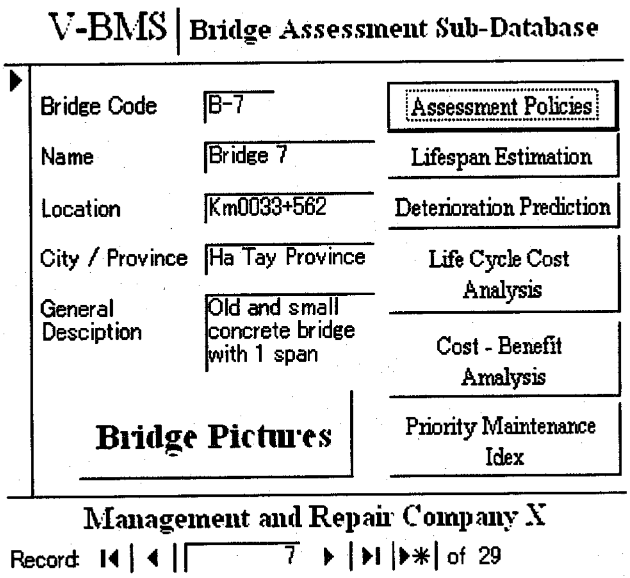

Fig.11. The *Bridge Assessment Sub-Database*

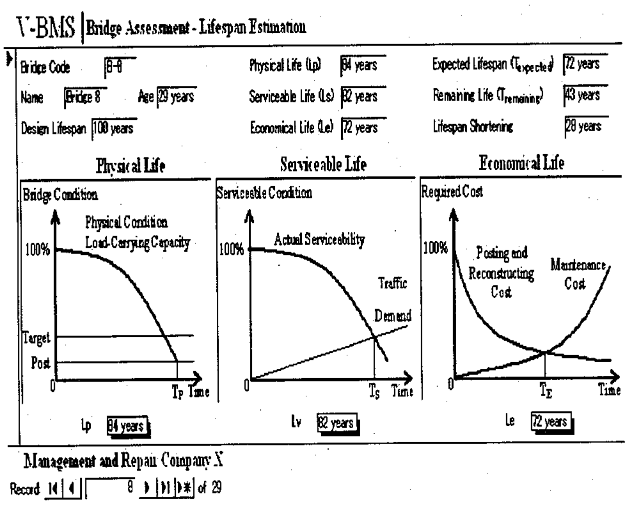

Fig.12. Output screen for the Lifespan Estimation

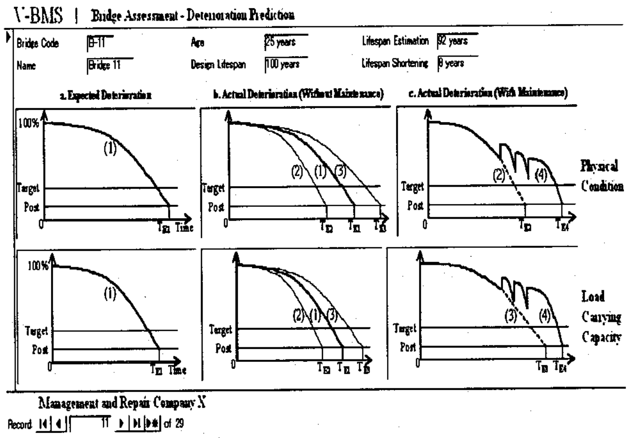

Fig.13. Output screen for the *Deterioration Prediction*

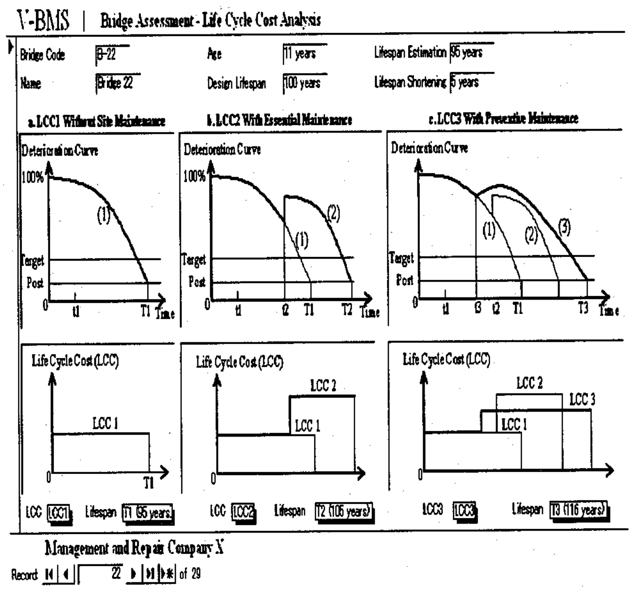

Fig.14. Output screen for the *Life Cycle Cost Analysis*

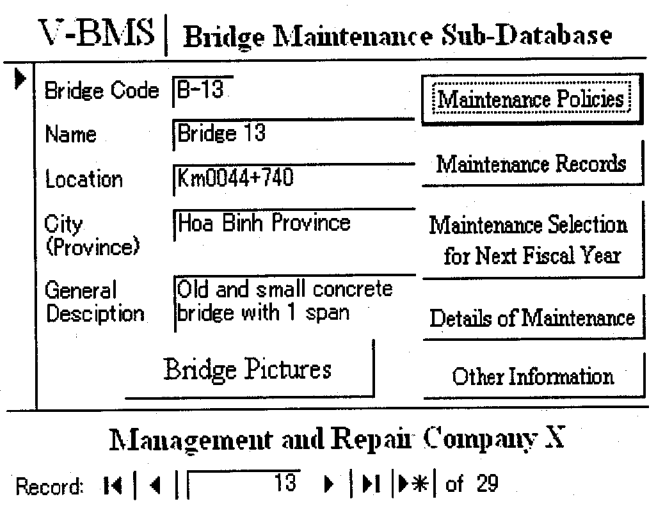

Fig.15. The *Bridge Maintenance Sub-Database*

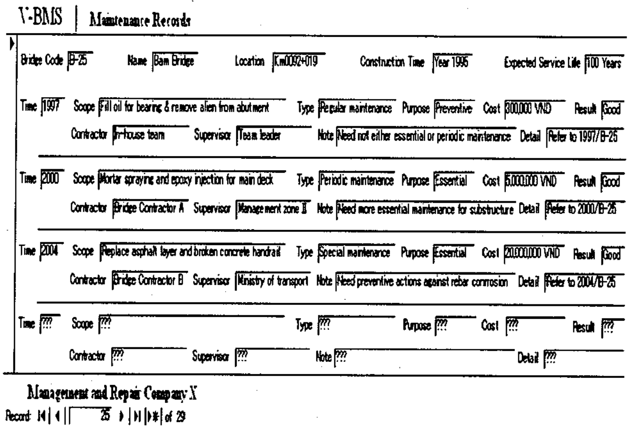

Fig.16. The *Maintenance Record*

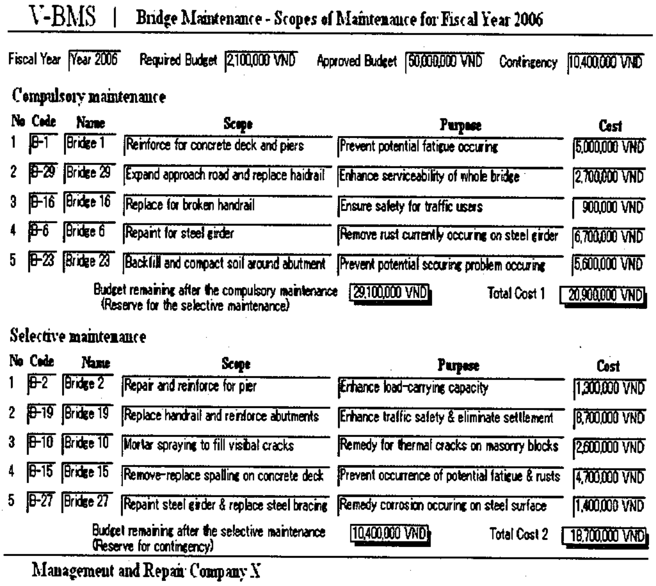

Fig. 17. The *Scopes of Maintenance*

(2) Scope of Maintenance

An important part of the maintenance module is to decide maintenance scope for next fiscal year. Firstly, all necessary works and its estimated costs (Table 7) should be listed by site inspectors. They are finalized by the company's management board that take in account for not only technical matter, but other aspects of social, environment, economy, etc., as well. As approval satisfies only 30-50% requirement, the management and repair companies therefore cannot carry out all proposed maintenance scope, but only necessary tasks. The proposed V-BMS divides necessary maintenance into compulsory and selective works. The compulsory maintenance encompasses tasks that must be urgently carried out in order to ensure minimum allowable level of safety and serviceability. Meanwhile, the selective maintenance is non-critical tasks currently. However if the budget is available, they should be carried out soon in order to prevent potential problems in the future.

In the example of the company X, required maintenance expense for the fiscal year 2006 is estimated for 121,100,000 VND (Table 7) while the approved maintenance budget is only 50,000,000 VND. In this situation, the company cannot conduct all required maintenance, but have to select for most necessary works only. Firstly, compulsory maintenance with total cost of 20,900,000 VND must be carried out on several bridges to ensure structural and traffic safety and to satisfy for other factors of the society, environment, economy, etc. As the budget remaining after the compulsory maintenance is 29,100,000 VND, the selective maintenance should be also carried out. Based on the pre-calculated maintenance priority index, bridges those have highest BP values will be selected to carry out site maintenance at next fiscal year (Fig.17).

5. Conclusions

This paper proposes a practical maintenance management system for highway bridges in Vietnam. By reviewing current status of existing bridges in terms of the physical quality and management practice, five outstanding problems are identified. In addition, several advanced assessment techniques (lifespan estimation, deterioration prediction, LCC analysis, and priority index) are also proposed in the new system. A PCs-based database that is the core of the proposed V-BMS is established. The paper considers if the proposed system is properly applied, it can either eliminate outstanding problems or minimize their adverse impacts. In order to make the proposed V-BMS compliant with the specific condition of Vietnam, the study simplifies the computerized database to apply at tactics level and does not require expensive infrastructures or superior knowledge. It therefore can run in normal PCs and will not generate high operational costs. Demonstration of the proposed V-BMS for a specific management and repair company in Vietnam is further carried out to prove the validity of the new maintenance management system.

In order to successfully apply the proposed V-BMS for highway bridges in Vietnam, the paper recommends testifying it on actual condition so necessary modification can be made. It is in order to prove the system appropriate with local condition of Vietnam and to make necessary improvement if necessary. Moreover, training for local Vietnamese in-house staffs in charge of handling the new system is also recommended to smoothly run the proposed system on actual maintenance management practice. Further research needs too to make the proposed V-BMS more robust with better automatically functions. Moreover, interlinks between databases of all maintenance management agencies throughout entire country of Vietnam should be set up for purpose of information shearing and strategically decision-making process.

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Received on September 10, 2006