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Bridge Management System for the City of Moscow

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ABSTRACT

Moscow Bridge Management System "MOST" controls the stock of 872 structures including bridges, overpasses, tunnels, pedestrian underpasses, and embankments.

"MOST" has been developed as the package of software in client-sever model. It subsumes procedural documents to describe the structures' management, including inventorying, inspection and deterioration models, optimal maintenance, repair and rehabilitation (MRR) assignments and budget planning.

To describe a structure "MOST" employs specially developed expandable catalogue of "standard structural elements" (SSE), to which corresponds a deterioration model, a set of several condition states, and a set of standard repair procedures. Unlike other existing BMS, "MOST" develops a bridge's inspection plan, establishing bi-directional correspondence between bridge drawings and the list of SSE in the database, which is extremely helpful for adequate repair assignments.

MRR activity and budget can be planned and optimized based on bridges' inspection data, obtained during Standard Inspection procedure. Plans can be built and reported for different groupings, such as a road network, selected group of bridges or even a group of SSE. The calculation is done in interactive mode, which also allows the user to change the criteria according to the user's needs. According to the experimental information about the bridge elements' actual lifespan, "MOST" uses non-Markovian deterioration models to predict the condition states of the SSE. Initial arrays of deterioration models and standard repair procedures effectiveness have been developed using the experience collected from more than 3000 bridges in Russia. Over time "MOST" will automatically improve the available data based on accumulated inspection results.

MOSCOW BRIDGE STOCK

The bridge stock of the city consists of 414 structures of different styles, sizes, and ages (figure 1). Over 90% of bridges are large costly structures, which require high attention and unconditional reliability. At the same time, an assessment of conditions of city bridges' shows them to score on average 3.5 points on a 5-point assessment scale. The average lifespan of bridge structures in Moscow is 35-40 years, despite of the fact that, Russian standards demand their design life to be 80-100 years.

One of the most important factors influencing fast bridges' deterioration is bad ecology in the City, i.e. high air pollution, large concentration of the aggressive ice-breaking chemicals and adverse winter, comparatively mild, with the great number of icing up - thawing out cycles. In those conditions the durability of concrete coating is 5-10 years, of concrete decks – 20-40 years, of metal decks – 40-60 years, and of bearing columns – 60-80 years. That is why expenses for seasonal repairs of Moscow bridges' exceed 30% of full maintenance cost (Figure 2). It is expected that the use of suitable BMS would contribute to increased bridge life through the optimization of MRR activities.

"MOST" SOFTWARE STRUCTURE

Bridge management system "MOST" has been developed as the package of software in client-sever model. It supports the user at every stage of MRR activity for entire inventory. Its development has been based on recent international experience in the field, considering such systems as Pontis, RAMBRO, BRIDGIT, MONSTR, and others. In addition to usual services provided by these bridge management systems, "MOST" concept offers:

- Working in client-server multi-users regime;
- Possibilities of Internet access;
- Address setting of repair procedures, taking into consideration the location of structural elements of a bridge;
- Creation of drafts and inspection schemes in ACAD format;
- Complex analysis of strain-stress condition taking in consideration the deterioration of SSE of the bridge;
- Correction of deterioration's forecast considering real wear rate of construction elements.

Basically "MOST" consists of 8 modules: Navigator, Inventory, Archive, General Catalogue, Inspection, MRR Optimization, Stress-Strain Calculations and Reference Book. All these modules are interconnected and data included in all of them form the unified database.

Navigator

Navigator is based on interactive map of the City, where all bridges are marked. The user can scroll the map going from one bridge to another. In the right side of the screen the user will find main information about the located structure, i.e. ID, name, length, area, design load, facilities carried and crossed, etc. (figure 3.)

Inventory Module and Archive

Once Navigator locates the bridge, all information about the structure can be conveniently found in the Inventory module using bridge name or ID number. The Inventory module shows the structure in details, including administrative data, geometry, design, structure units, photos and more. It provides the possibility to precede special inquiries by 50 different "key" parameters of the bridge. Being directly connected with Archive, Inventory module also delivers electronic drawings of the bridge in ACAD or BMP formats.

General Catalogue

Like "Pontis" bridge management system [1], MOST presents a bridge as an assemblage of standard structural elements (SSE), to which one of several condition states (CSt) are assigned. Over time, SSE change CSt from better to worse according to deterioration models (DMd). MRR activity is generated by standard repair procedures (SRP). SRP is assigned according to a system of special rules and is associated with CSt.

Specially developed totalities of SSE, CSt, DMd, SRP form the General Catalogue of "MOST" software. Up to now, the totalities include:

- 221 standard structural elements;
- 860 condition states;
- 54 deterioration models;
- 126 standard repair procedures.

Unlike other existing BMS, "MOST" allows the unlimited widening of the size of stated totalities, and the software provides the opportunity for new elements' input. "MOST" is scaleable for the description of complex bridges as well as specific structures in the user's inventory.

Standard Structural Elements

For the purposes of appropriate analysis and MRR planning "MOST" stores bridge data at one level of detail and presents the whole structure as a set of standard structural elements. However, for clarity and convenience of the description, a bridge can be divided into one or more Structural Units prior to SSE assignment. General Catalogue recommends 21 types of Units of different duties. Within each unit (for example, deck) inspector appoints a number of Structural Details (for example: beams, joints, railing, etc). Each detail shall be described by the set of SSE: structure, material, cover and connection (for example: handrail, cast iron, paint, screws). Any SSE, except for an ID number and quantity, shall be characterized by its accessibility, which describes technological difficulties of its treatment. For the purposes of MRR optimization, "MOST" integrates all identical SSE at the bridge into one "planning cell" that shall be considered an independent object. Freedom of SPR assignment for it will be limited only by special rules, if applicable. The classification of SSE includes 9 groups (Table 1).

Deterioration model and Condition States

Obviously, SSE ability to work declines over time, but criteria of functional disturbance for different elements vary. Nevertheless, in order to secure bridge's reliability, each SSE has to be treated before its wear will exceed a certain value determined as "maximum acceptable" and suitable from the point of view of influence on the structure's load capacity or/and exploitation's safety. That is why for each SSE General Catalogue sets a value of maximum acceptable wear ($\mathbf{I}_{\mathbf{max}}$) and describes the quantitative criteria of its determination usable during the inspection process. In assumption that $\mathbf{I}_{\mathbf{max}}$=100%, based on the analysis of experimental data about the entire bridge network's reliability and structural failures, the normalized wear (**I**) of the SSE at any given moment of time (**t**) can be described as:

$$\mathbf{I = [exp(\lambda * t) - 1] * 100\%}$$

Here **λ** – normalization ratio, which has to be calculated from the boundary conditions:

$$\mathbf{I_{max} = 1 \;;\;\; t(I_{max}) = T}$$

In the last equation **T** is the average durability of SSE, obtained from experimental data.

For each SSE "MOST" assigns 5 condition states, directly connected with the level of the element's wear (Table 2). General Catalogue provides appropriate descriptions of corresponding symptoms, suitable for the inspection purposes.

According to deterioration model, wear intensity increases in time (figure 5.) This is the first reason to investigate the benefits of early repairs of important structural elements.

Of course, the accuracy of the condition state's forecast for a particular SSE, based on the deterioration model mentioned above, depends on real variation of "**T**" value. The analysis of corresponding data acquired from utilization of approximately 3000 Russian bridges shows that for elements of the same type belonging to different structures lifespan variation may exceed 30%. In order to reduce the miscalculation of this forecast, "MOST" corrects "**T**" values for a particular bridge, considering its inspected history, as follows.

Suppose that for a type of SSE (ID #**i**) deterioration model is described with the average (standard) durability $\mathbf{T_i}$. Suppose further, that at the time $\mathbf{D_X}$ passed from the beginning of the structure's utilization, the measured wears for "N" SSE of this type assigned for the entire bridge can be presented as the array

$$\mathbf{\{ I_{i1} \ldots I_{ij} \ldots I_{iN} \}}$$

From this array average real wear $\mathbf{I_{iRX}}$ can be calculated. Then, according to deterioration model, the adjusted normalization ratio for any SSE (ID #i) on the entire bridge would be

$$\mathbf{\lambda_{iR} = D_X^{-1} * \ln(1+I_{iRX} / 100\%)}$$

Based on the above equation, the corresponding corrected "**T**" value can be obtained. Taking into consideration possible accuracy of wears' measurement, it is clear that adequate use of described adjustment procedure requires that

$$\mathbf{D_x > 0.2 * T}$$

Standard Repair Procedures

"MOST" utilizes the totality of SRP developed in correspondence with Moscow bridges' MRR practice, which uses three different types of repair actions:

- Maintenance and routine care;
- Preventive repair, applicable for SSE with condition state better than 2;
- Supporting repair, applicable for SSE with condition state worse than 2;

- Major repair and rehabilitation, applicable for SSE with condition state worse than 2.

Each SRP is characterized by its own technological procedure described in the General Catalogue and two parameters: estimated price and time effectiveness ratio (TER), which are calculated based on Moscow bridges' MRR experience. If SRP is applied to SSE, "MOST" automatically modifies the deterioration model for this standard structural element, as shown at the Figure 6.

Inspection module

This software module supports the procedure of any bridge's Standard Inspection in terms of General Catalogue.

Standard Inspection for any bridge shall be carried out at intervals not exceeding 2 years and shall replace the routine superficial inspection for that year. It consists of visual examination and required measurements of all accessible parts of the bridge without the use of special access equipment apart from ladders and scissor lifts. This inspection shall be carried out by personnel competent to judge the seriousness, extent and condition of defects that may affect the load carrying capacity of the units inspected. For each SSE an exact condition state and accessibility shall be assigned. A photographic record shall be made. If judged necessary, a Major or Detailed Special Investigation shall be initiated.

Prior to the inspection, it is necessary to build out an Inspection Scheme that establishes bi-directional correspondence between bridge drawings and the list of SSE in the database. For this purpose "MOST" provides the special software, which allows direct assignment of SSE onto the ACAD drawing. If no ACAD-drawing is available, the user can build the Inspection Scheme utilizing previously scanned paper-based draft as a template.

"MOST" presents inspection results in 2 forms: "Detailed bridge's structure" which locates all SSE in Structural Units, and "Inspection results" which shows SSE condition states and access categories. Within the boundaries of Inspection module it is also possible to evaluate the overall condition of the structure by calculating average condition state's for each SSE and Structural Unit or "Health Index" [2].

MRR optimization module

This module provides short-term and long-term:

- Forecast of bridges' condition state;
- Budgetary planning;
- MRR planning and SRP assignments.

Plans can be built for different groupings, such as a bridge network, a selected group of bridges or even a group of SSE, providing either a general report for the grouping or an optimal SRA/cost recommendation for each SSE of each bridge.

MRR optimization seeks to determine the number of SRP that should be applied to each SSE during a period of time in order to minimize the life-cycle costs while preserving the entire bridge or bridges' network in a given condition state.

The total long-term MRR activity cost is the sum of the initial (first-year) SRP cost and the discounted sum of the future costs of SRP in the following years. The totality of possible SRP combinations is growing also because of the opportunity to repair some SSE in different condition states. This is an additional chance for the optimization, because the specified yearly cost of MRR activity is a non-linear function of SSE wear level (Figure 7).

Analysis shows that optimal MRR strategy can vary depending on many specific factors, such as the worst SSE condition state allowed, expected bridges' lifespan, budgetary constrains, discount and inflation rates, etc. (illustrated by Figure 8). "MOST" allows the user to adjust those factors in a dialogue mode.

While generating an optimal MRR scenario "MOST", being ruled by the cost factor, assigns the exact SRP for each SSE in the investigated bridges' network. However, the Agency has to plan MRR activity taking into consideration not only costs but also many other circumstances. That is why "MOST" allows the user to customarily change SRP assignments in a special procedure. After this modification, the new budget and corresponding forecast for the corrected strategy is automatically calculated.

Stress-Strain Calculations

Elemental stress-strain calculations determining a bridge's load capacity can be produced using a STRAP-based finite-element module. The development of finite element parameters also can be based on inventory and inspection data.

IMPLEMENTATION STATUS

The first version of Moscow BMS was completed in January 2002 and is being used by Gormost, an agency of Moscow City responsible for bridge maintenance. According to the Agency, "MOST" forms the friendly environment for the inspection, planning, and analysis. Using the program, the Standard Inspections on 414 Moscow bridges had been performed during six month. Inventory and historical information, computer-based drawings, inspection results and project plans are conveniently maintained in "MOST" database. Information can be presented and extracted in different ways, either on screen or on paper.

This year, "MOST" is being expanded for the maintenance of transport and pedestrian tunnels, embankments and other structures under Gormost supervision.

ACKNOWLEDGMENT

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2. R.W. Shepard and M.B. Johnson. California Bridge Health Index, IBMC-005, California Department of Transportation // International Bridge Management Conference, Denver, Colorado, 1999, Preprints, Volume II, K1.

List of tables and figures

TABLE 1 Groups of SSE used by "MOST" software

Group #	Group Name	Qty of SSE types
1000	Materials	26
2000	Connections	11
3000	Coatings	8
4000	Road slab, waterproofing and drainage systems, parapets and handrails	42
5000	Bearings and foundations	18
6000	Decks	80
7000	Stairways, retaining walls, embankments	17
8000	Other elements, including architectural details	11
9000	Equipment	8
Total quantity of SSE types		221

TABLE 2 Condition states assigned for the SSE

Condition state's ID	Describtion	Normalized wear
1.0	"Like new"	<20%
1.5	"Good"	<40%
2.0	"Normal" - no limits for bridge's load capacity	<60%
2.5	"Critical" –some limitations for bridge's load capacity or traffic restrictions apply	<80%
3.0	"Bad" – further usage is allowed only if considerable limitations for bridge's load capacity or traffic restrictions are applied	<100%

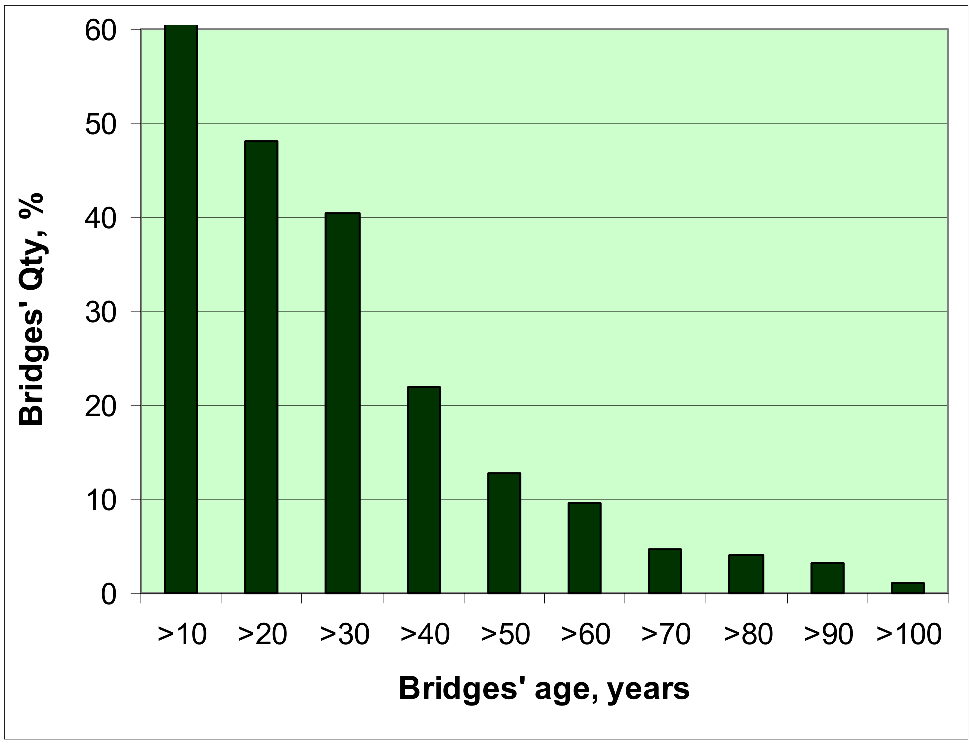

FIGURE 1a Moscow Bridge stock. Distribution of structures by age

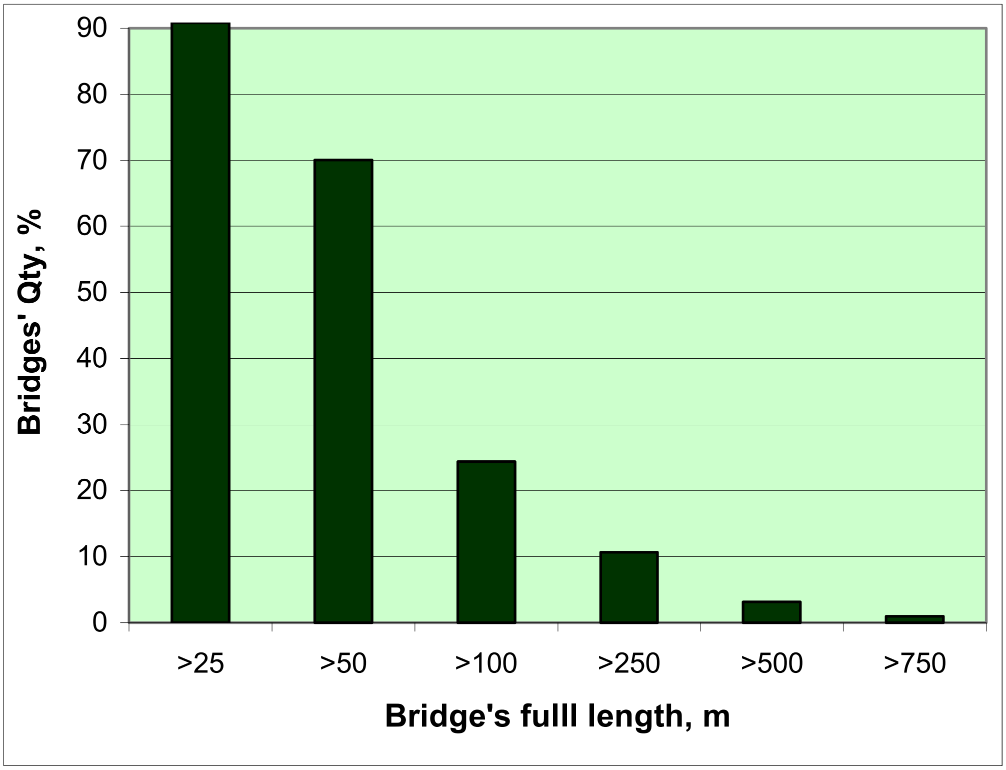

FIGURE 1b Moscow Bridge stock. Distribution of structures by size

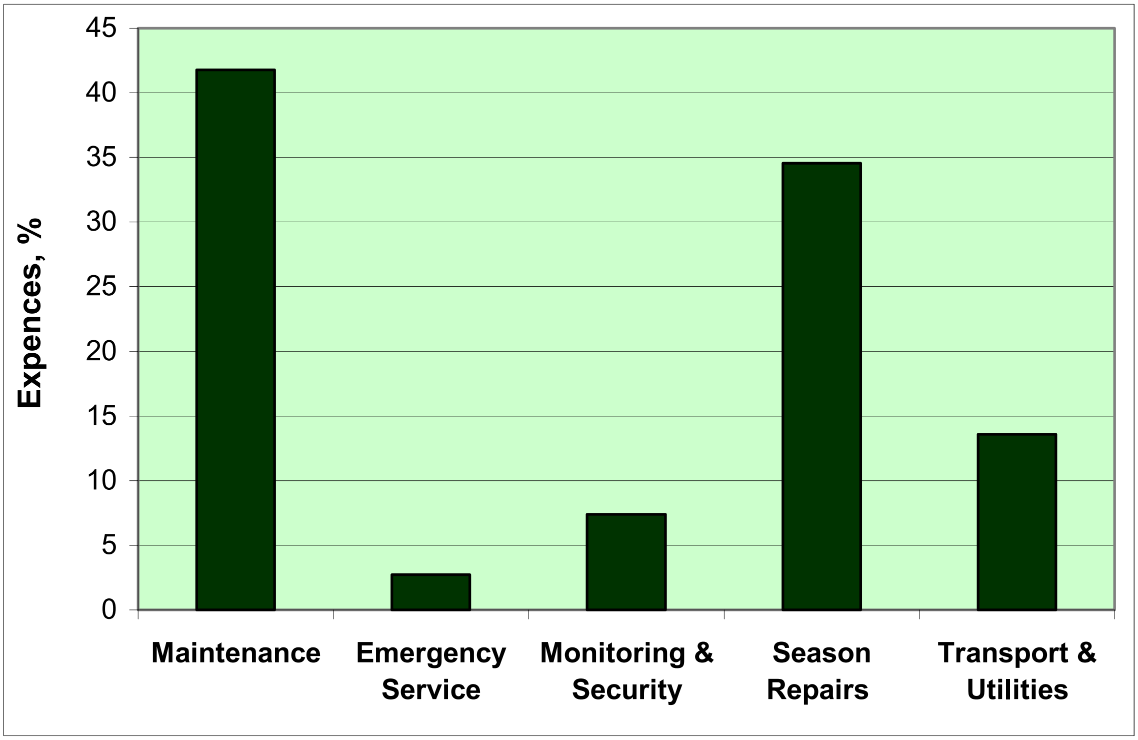

FIGURE 2 Moscow Bridge stock. Expenses for structures' routine care.

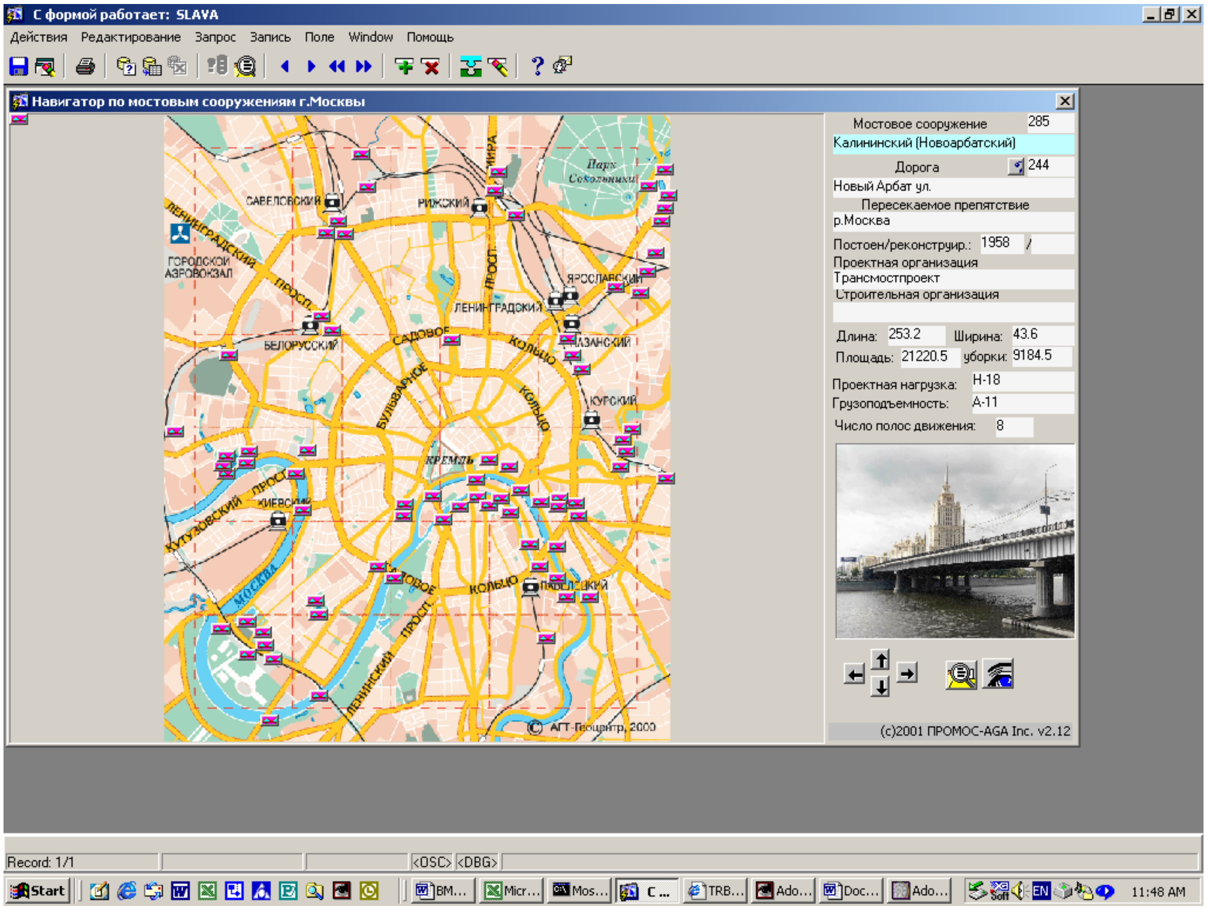

FIGURE 3 “MOST” software structure. Navigator

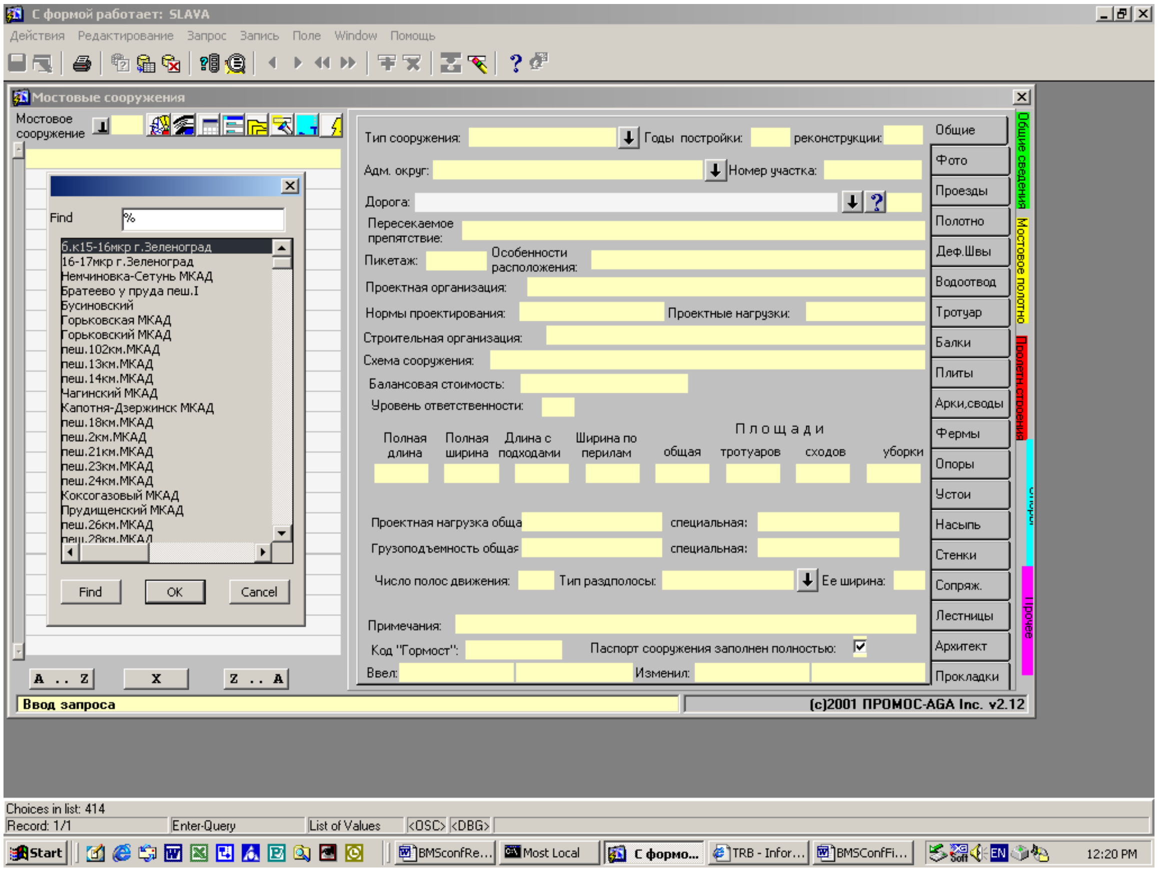

FIGURE 4 "MOST" software structure. Inventory module

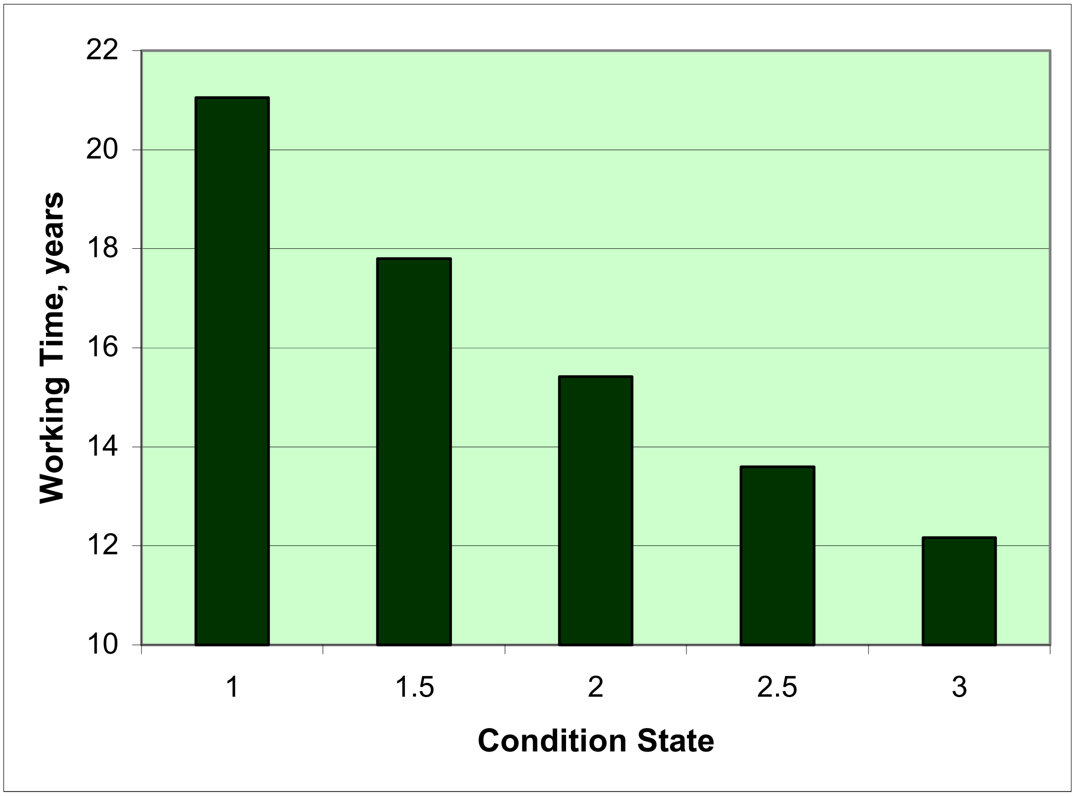

FIGURE 5 SSE working time in different condition states (an example is SSE #1020 "Reinforced Concrete")

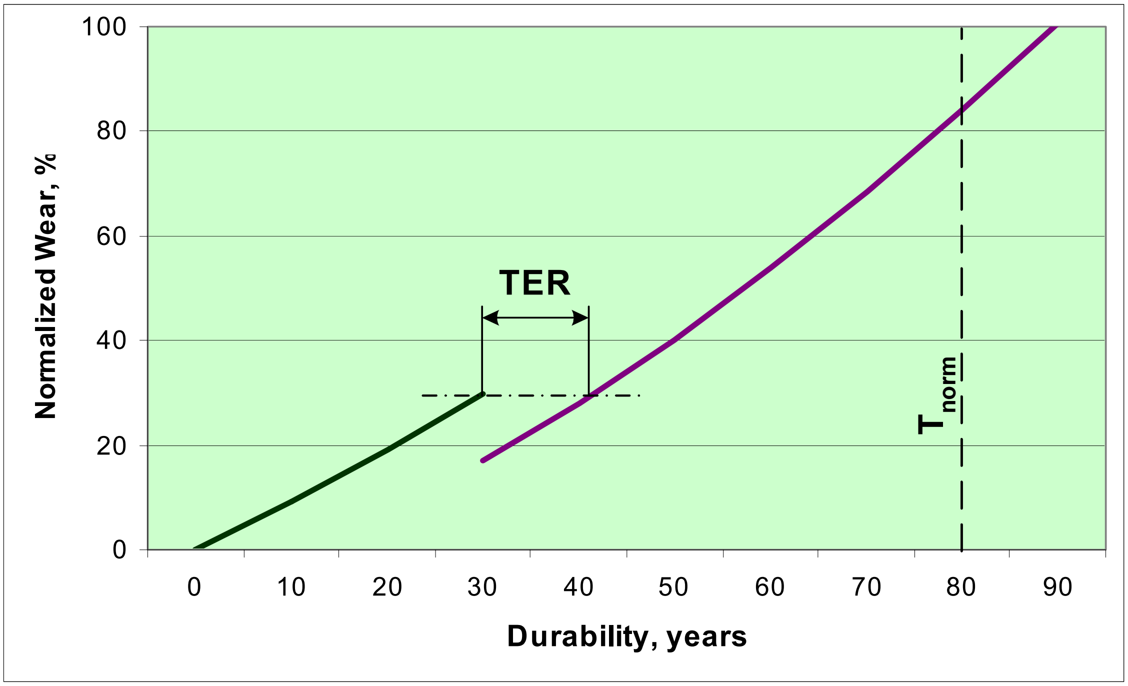

FIGURE 6 Deterioration model for SSE ID #6000 "Reinforced Concrete Beam" modified because of SRP ID #1021 "Injection" application

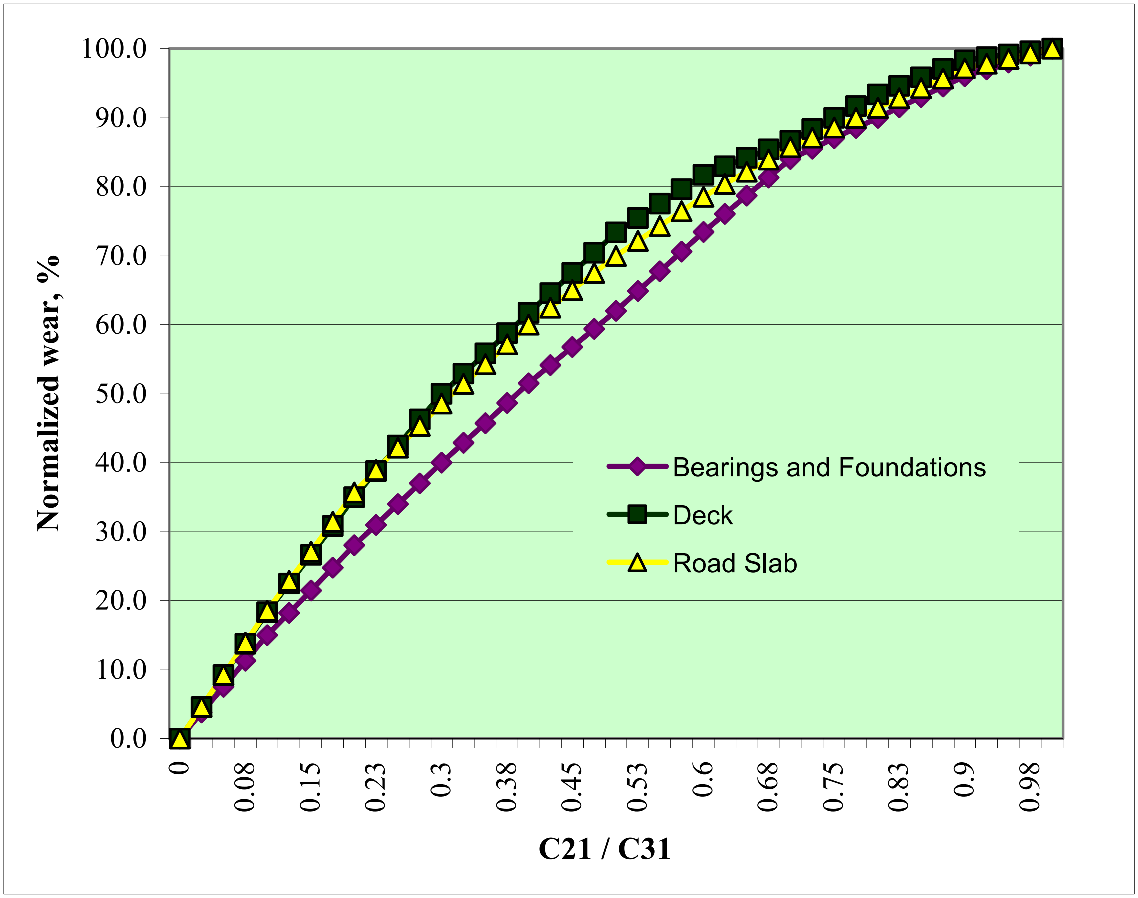

FIGURE 7 Specified SRP cost (C21) proportionally to the replacement cost (C31) as a function of SSE wear's level

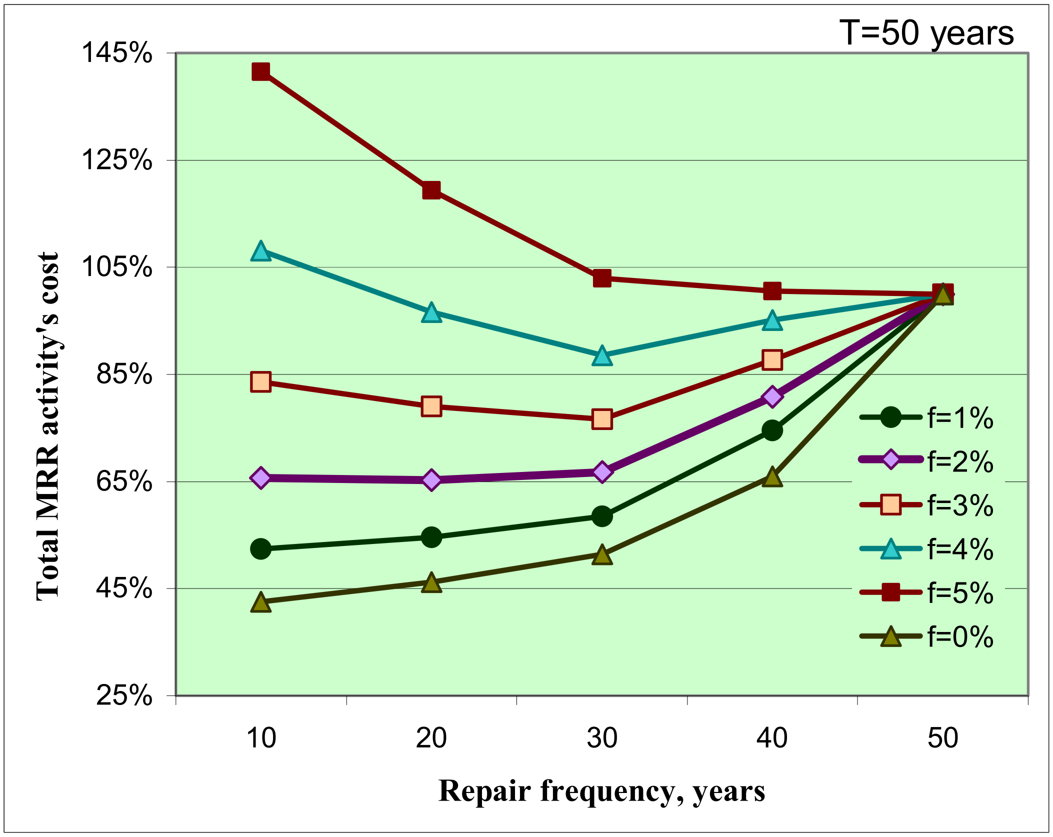

FIGURE 8 Total MRR activity cost depends on repair frequency and discount rate (f)