Distinctive Features of the Swiss Road Structures Management System

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ABSTRACT

Ongoing efforts to develop a comprehensive road structures management system in Switzerland have resulted in a project called KUBA-MS. The system is based on ideas underlying the AASHTOWare Pontis System but distinguishes itself in several features, reflecting differences in Swiss and US maintenance practices. The paper describes the general structure of the system and describes its distinctive features. Aspects of system development and data management are outlined, along with the current implementation status.

ROAD STRUCTURES IN SWITZERLAND

Switzerland has a dense network of federal and cantonal highways, which is further augmented at the lower level by an even denser network of communal roads. Due to Switzerland's mountainous topography, these roads include a large number of road structures. Currently the network of federal highways extends to approximately 1600 km, containing a total of about 10,000 road structures including 3100 bridges. This is the current status, covering roughly 90% of its final extension of nearly 1800 km. The network of cantonal highways and communal roads is more than 70 000 km long, the cantonal highways alone having 14,000 road structures including 10,000 bridges.

The major part of the infrastructure was constructed from 1960 to 1980. With the road network's increasing age, the responsible authorities are confronted with the challenge of assuring financing for the necessary maintenance work in a time of both tight budgets and ecological constraints.

ORGANIZATIONAL SETUP

The responsibility for the preservation of the federal highways lies with the cantons. Preservation actions have to be approved by the Swiss Federal Highways Office (SFHO) since they are substantially funded by the SFHO.

In view of growing demands for preservation of the infrastructure, the development of a software-based inventory system was initiated in 1987. This effort resulted in an inventory system called KUBA-DB (from the German: KUnstBAuten-DatenBank = road structures database). In 1992 the development of the management system KUBA-MS (from the German: KUnstBAuten ManagementSystem) was launched.

This development work was influenced by the following considerations:

- The bridges in Switzerland exhibit a large variety of structural systems and a myriad of structural details, which render a classification of bridges and their elements, as well as preservation actions, comparatively difficult.
- The development documentation had to be multilingual, since the official languages of Switzerland are German, French and Italian[1] at least all user-oriented documents and, of course, the software application itself had to be multilingual.
- The development had to be coordinated with the SFHO as well as with the cantonal authorities.
- Cantons differ considerably in the way they manage their structural inventories, which results in different requirements for software support.

The above issues lead to considerable organizational overhead, but the real involvement of all user groups was seen as essential for the success of the future system.

TOWARDS A COMPREHENSIVE MANAGEMENT SYSTEM

The outline for a Swiss road structures management system is given with the development of a so-called master concept (Hajdin, 1995). This master concept became the basis for all subsequent work. The ideas contained in this document represented the current state of the art in the field of management systems, adapted for Swiss conditions. Based on ideas underlying the AASHTOware PONTIS system, KUBA-MS is conceived to overcome insufficiencies of the 1995 version of PONTIS, especially on the project level.

Requirements

In collaboration with the authorities responsible for road management, the main objectives for the future KUBA-MS system were defined as follows:

- Among several plausible preservation policies, the system shall identify the economically optimum preservation policy. A policy defines the type of action and the damage level at which this action should be performed. All preservation policies meet required safety and service levels. In case a non-optimum policy is pursued, due to budget restrictions or other constraints, the economic consequences and the effect on the average condition of the structures should be indicated.
- The selected preservation policy yields a list of projects, for the present and for future periods. Additionally, improvement projects to remedy functional deficiencies (e.g., width, clearance) are added to the list. The projects include both agency and user

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[1] It has been decided that the fourth language is not going to be supported by the development.

costs. They are optimized with regard to their life-cycle costs, yielding a working program for any subset of structures.

The costs of data acquisition should not exceed 10% of the regular inspection costs.

Framework of the Swiss Road Structures Management System

The basic approach for the planning of preservation activities can be summarized as follows:

1. Data acquisition

Based on the information stored in the inventory system, inspection data on structures is collected. The data describing the condition of a structure is the starting point for the planning of preservation actions. In order to support the planning of improvement actions, the functional properties of a structure and the relevant traffic data are also subjects of the data acquisition.

2. Condition forecast and determination of optimum preservation actions

Besides the current condition data, the planning of preservation actions requires a condition forecast. The preservation of a structure can include maintenance, repair or rehabilitation actions. Each action is distinguished by its costs and its effectiveness. By comparing these actions in a life-cycle analysis, optimum actions for all conditions can be found.

3. Improvement actions

Structures that do not meet functional requirements call for improvement. Based on the data collected in the data acquisition, these structures can be identified, and appropriate actions to overcome insufficiencies can be defined. In order to justify the improvement, the benefit for road-users resulting from the action is estimated.

4. Optimization on the project level and working programs

The generated preservation and improvement projects are compared to each other in order to find the economically optimum variants. The analysis can be extended by including road-user costs. Actions required to maintain structural safety and serviceability are prioritized without entering the optimization. The chosen projects are used for the planning of resources in the current period. In the optimization on the project level, single structures and groups of structures can be considered.

5. Strategic planning on the network level

By using the condition forecast and the determined optimum preservation actions, the effect of budget restrictions on medium- and long-term preservation costs, and on the average condition of the entire population of structures, can be studied. These calculations can be effectively represented graphically and therefore are well suited to communicate financial needs to the public.

Distinctive Features

The distinctive features of the system can be summarized as follows:

- From the beginning, it was intended that the system address all road structures, not only bridges. The topography of Switzerland requires a large number of bridges but even more retaining walls, culverts and other protective structures.
- The optimization is performed on several levels. A procedure is used to determine the economically optimal long-term preservation policy and to estimate the medium- and long-term costs at the network level. On the project level, well defined projects including preservation and improvement actions can be generated and optimized with regard to life-cycle costs.
- In the decomposition of structures, a so-called "segmental" approach is chosen. A structure is first divided into elements, which are classified according to their element type and construction type. In order to better account for differences in exposure to environmental influences, structural function and geometrical setup the elements are further subdivided into segments.
- When calculating the future condition of certain elements, their performance in the past is taken into account in order to generate preservation actions on the project level. This yields more accurate results on the project level.
- The deterioration processes are basically assigned to materials, not to element types. This leads to a reduction in Markov chains and an increased data sample for the determination of the coefficients of the corresponding matrices.
- In order to consider differences in the decay of segments subjected to the same deterioration process but different exposure levels, influence matrices are used to adapt the Markov chains.
- A conversion function is used to calculate the portion of the total extent of a segment which is assumed to be affected by a preservation action from the portion which is deteriorated.

DECOMPOSITION, CLASSIFICATION, AND CONDITION ASSESSMENT

Structures, Elements, and Segments and their Classification

A systematic decomposition of road structures into elements was already foreseen in the road structures inventory system KUBA-DB. Both structures as well as elements are classified using elaborate catalogs. Elements are primarily classified using the catalog of element types and the catalog of so-called 'construction types.' For the example of a column in reinforced concrete, the 'column' is the element type and 'reinforced concrete' the construction type. In addition to the construction type, the inventory system also allows storage of each material used in an element, which would be 'concrete' and 'reinforcement steel' in the example. The definition of basic information on structures, i.e., decomposition and classification, is part of the primary data acquisition.

The KUBA-DB catalogs could not be used directly for the management system since they were far too detailed for financial planning. Regarding the catalog of element types, only those element types are required that enable a reasonable approximation of preservation costs. In order to identify these cost-relevant element types, a detailed study of performed actions is currently underway.

After the decomposition of structures into elements, the elements are further divided into segments. An element can contain one or more segments, depending on the geometry, size, structural role and prevailing environmental conditions. Elements are classified by their element type and construction type, while segments are characterized by their extent and by their exposure to environmental influences. The segments of certain element types require, besides their extent, additional data addressing their design particularities (see section "Preservation Actions"). Figure 1 shows the hierarchic levels used in the decomposition of structures.

The idea of subdividing elements was adopted for the following reasons:

- A relatively detailed decomposition of a structure can be necessary due to the geometry, size, structural role and environmental conditions. In the existing road structures inventory system KUBA-DB, elements were already ascribed a large number of attributes. A separation of existing elements in order to account for differences in environmental influences or the structural role would have caused too much work on the existing database.
- The two-level hierarchy gives the user more flexibility in decomposing a structure. No changes are required for structures already contained in the database, and additional data for segments can easily be added.
- In the existing database new elements are distinguished due to their location in the structure. For example, identical abutments (left and right) are regarded as two elements, although they have exactly the same attributes. With segments this is no longer necessary and thus primary data acquisition is facilitated.

Assessment of Present Functional Properties and Traffic Data

The functional properties of a structure, i.e., the road it belongs to (lane-width, number of lanes, presence of a security lane, vertical clearance, weight limits, etc.) are of major interest to a highway agency. Based on this information it can be quickly determined whether a special transport can use a route, for example, or the most significant obstacles to traffic flow can be identified. These physical characteristics of a structure are stored in the inventory system, accompanied by the required standard. In the context of the management system, the information is very useful as a basis for the improvement model.

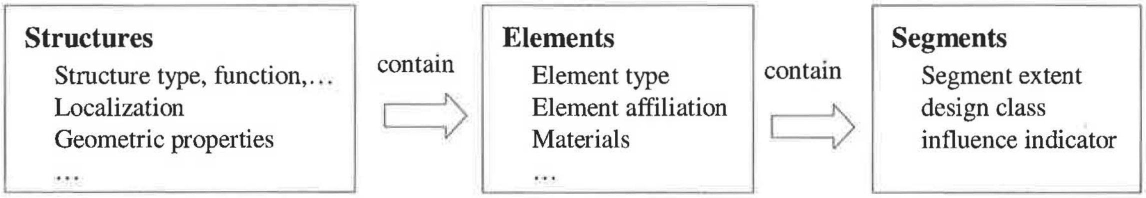

Figure 1: Levels in the decomposition of a structure and important attributes.

In addition, the characteristic traffic data of the road is required. This data determines the need for an improvement to cope with traffic requirements. Additionally, the user-cost model relies on the traffic data.

Condition Assessment During Routine Inspections

In KUBA-MS an approach to condition rating has been taken that is similar to the one taken in Pontis, which describes the type, severity and extent of a damage. Type of damage is, in this context, a synonym for the deterioration process, which characterizes the appearance and the development of the particular damage.

In agreement with widely applied practice, a scale of five condition states was adopted, ranging from 1 (good condition, i.e., no damages) to 5 (alarming condition, i.e., urgent actions necessary). The descriptions of all condition states for the deterioration processes, together with representative photographs, are included in an inspection manual.

The actual condition of a structure, i.e., all damages detected in an inspection, is the starting point of every preservation action. With regard to the planning of preservation actions, an important distinction is made at the level of the damages:

a) "Regular damages" are caused by a physical-chemical deterioration process (for example, corrosion) and display certain regularities concerning possible preservation actions.

b) "Irregular damages" do not necessarily originate from deterioration processes and, thus, the rules for regular damages do not entirely apply.

c) Another category is damages which are caused by specific, single events (collision, fire, etc.).

Category c) is generally not considered in the system because such damages usually require immediate actions that are managed in a completely different manner. Minor damages according to c), which are not repaired, may enter the system, however, as parameters that may influence deterioration processes.

The damages according to b) cannot be assigned to a deterioration process. They have to be described individually, accompanied by pictures, if necessary. The damages ascribed to a), relating to deterioration processes, are by far the most common cause for preservation actions. They are dealt with in the preservation model described below.

PRESERVATION MODEL

The aim of preservation is to maintain or restore an acceptable level of service and functionality of a structure. Expressed in more concrete terms, preservation means the elimination, by means of structural actions, of damages that reduce or endanger the functionality or level of service. A management system automatically links damages to technically plausible preservation actions and their corresponding costs (Figure 2).

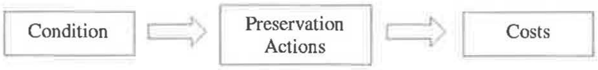

Figure 2: Generic model for the planning of preservation actions and related costs.

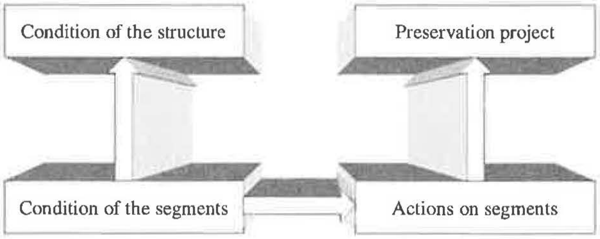

Figure 3: Generic model of project generation.

In order to achieve an acceptable level of accuracy, the step from the condition of a structure to plausible preservation projects, including costs, is made on the level of the elements. Consequently it is necessary to define those element preservation actions that are best suited for application to a particular condition.

Element Preservation Actions

A key element of a management system is its knowledge base of preservation actions. These actions are characterized by their unit costs and effectiveness. The cost predictions generated by the system depend on this data. Feasible element preservation actions are listed in a catalog, usually referred to as a catalog of actions. The catalog is the result of a statistical analysis of executed preservation projects. This catalog is subject to changes reflecting developments in construction technology.

Unit Costs

The unit cost describes the cost of an action applied to one unit of a segment. Unit costs not only include direct costs for materials, labor or scaffolding, but also indirect costs like those for installations, planning or traffic control. Thus very similar actions can have different unit costs, depending on the element type. Certain element types require higher expenses for scaffolding or traffic control than others.

A regular update of this data is usually required to maintain the accuracy of the system. The costs of executed projects are split to affected cost-relevant elements yielding a basis for calculating a unit cost for a particular preservation action.

The unit costs refer to a specific measurement unit. The unit for preservation work on steel elements, for example, is the square meter [m^2], i.e., the surface area. This unit has to be the same unit used for the condition rating.

It should be noted that unit costs include expenses for all works related to an action. For example, the rehabilitation of the upper side of a bridge deck includes replacement of the pavement as well as re-sealing. If the costs of this replacement work are not included, the optimization on the element level will yield incorrect results.

The application of unit cost in its simplest form has two limitations:

a) It is not always possible to use the same measurement unit for rehabilitation and replacement actions. When replacing steel elements, for example, the unit for cost estimates is the weight in tons, not the surface area in square meters. This makes it difficult to compare the actions on the basis of a common unit.

b) In some cases, the cost of a preservation action cannot be based only on a unit. For bearings, for example, it is not only the number (unit), but also the design load that governs the costs.

In order to overcome these restrictions the following approach is chosen:

ad a) Replacement actions are not always included in the optimization on the element level. Optimization on the element level generally compares no action to minor repairs up to major rehabilitation. For those element types that have the same unit for rehabilitation and replacement actions, e.g., pavements, sealing, bridge decks, bearing and joints, replacement is included. For other element types, like columns, girders, abutments or retaining walls, replacement is not considered on this level.

ad b) For those element types where the unit does not define the costs with sufficient accuracy, the criteria used for the design (design particularity) are added. For bearings and joints it is the load-bearing capacity and maximum opening that govern unit costs. Three classes for the design particularity are defined, and optimization on the element level is performed for all classes.

Action Effectiveness Model

If actions are taken, there is an improvement in condition state, represented by transition probabilities. These transition probabilities specify the effectiveness of the action. This approach considers the empirical knowledge that repair and rehabilitation works often do not restore a segment to condition state 1. Although the segment may look practically new, it deteriorates more quickly than a newly constructed segment. By redistributing less than 100% to condition state 1, a pseudo-accelerated deterioration is simulated.

The effectiveness model has limitations for actions, which slow down the deterioration process. Certain preventive maintenance actions can significantly affect the deterioration process, for example, by addition of a protection layer.

Markov Chains and Condition Forecast

The condition forecast makes it possible to generate preservation projects for any given period in the future. The forecast requires a model that simulates the future condition of a segment, given the current condition and the likely environmental influences.

KUBA-MS uses Markov chains for the condition forecast. Markov chains are able to simulate a condition forecast stochastically. Each deterioration process defined in the system has its own, characteristic Markov chain. The Markov chains[2] are calculated and

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[2] Markov chains are defined by so-called transition matrices which are often referred to as Markov matrices.

updated by a statistical analysis of the condition data collected during routine inspections. This enables a self-learning process and results in higher accuracy of the condition forecast.

Segments subjected to the same deterioration process can behave differently. In order to consider these differences, each segment is attributed a so-called "influence indicator." Three influence indicators are used: favorable, average and unfavorable. The indicators express that the concerned segment exhibits slow, moderate or fast deterioration.

Segments are supposed to have a favorable influence if they are not directly exposed to weathering and not contaminated with chemically aggressive substances, i.e., chlorides. An average influence corresponds to a usual exposure to weathering and chlorides, an unfavorable influence to a high exposure. The simultaneous action of two deterioration processes is also accounted for by an unfavorable influence. Finally, a segment may have defects due to poor construction or accidental damages. These defects can be considered by an unfavorable influence indicator as well.

The effect of the influence indicators is implemented by adding so-called 'influence matrices' to the transition matrices of the Markov chains (Figure 4).

Use of Historical Data

For some element types the application of Markov chains does not yield useful results on the project level. This can be explained in the example of bearings. The information that 70% of all bearings will be in condition state 2 and 30% in condition state 3 is meaningless when a single bearing is concerned. Bearings are only rehabilitated as a unit, and not in percentages. As soon as the concerned bearing has been inspected at least twice, its past behavior can be used to estimate condition forecast. Using this historical data, it can be determined whether the bearing is more likely to be within the 70% of bearings not requiring an action, or within the remaining 30% requiring an action.

Optimization on the Element Level

The objective for optimization is to render the performance of the system as independent of the number of structures as possible. The chosen approach is based on a recursive formula, which allows optimizing the preservation of a unit of an element type with regard to a limited number of actions. The minimization of life-cycle costs leads to the optimal preservation policy that provides a set of actions, one for each condition state, and indicates the life-cycle costs for applying this policy. The applied method is often referred to as the "Markov Decision Process."

Despite its convincing capacity to yield life-cycle costs, the Markov decision process has some disadvantages. The model is neither able to consider actions caused by irregular damages, nor to include user costs. Additionally, the advantage of actions

$$[M]+[N]=[R], \qquad 0 \le r_{ij} \le 1, \qquad 0 \le \sum_j r_{ij} \le 1$$

[M] : Markov matrix, [N] : influence matrix,
[R] : modified Markov matrix

Figure 4: Application of the influence matrix.

significantly slowing down a deterioration process can only be modeled by complicating the mathematical formulation considerably.

Optimization on the element level has to be performed in KUBA-MS for a large number of combinations of element types, design classes, deterioration processes and influence indicators. The result for each combination is an action set containing the optimum action for each condition state and the costs per unit for an infinite number of periods, during which the optimum policy is pursued (Figure 5). These unit costs are used to calculate future costs incurred after an action has been completed, and therefore they are referred to as "unit successive costs."

The results of the optimization on the element level are used in the two main planning modules:

- In optimization on the project level, the optimum action set is required as well as the unit successive costs.
- In strategic planning on the network level, the optimum preservation policy can be used to calculate the financial needs for applying the policy on the network level.

Determination of the Extent of Action

In an early state of development, simple tests were conducted to verify the capability of the system to predict future costs of preservation projects with acceptable accuracy. The results showed that the real costs were consistently higher than had been expected according to the system estimate. The reason was found in the extent of the element preservation action. This was often substantially higher than the deteriorated extent. This could be explained by the fact that once an action is taken, it is plausible not only to repair damages causing the action, but also less severe damages, assuming that these parts will deteriorate further in the near future. On the other hand, no action will be taken for damages not affecting the safety and covering only 5% of a segment, even if the optimum policy demands it.

In order to account for the disproportional relationship between the deteriorated extent and the extent of action a conversion function is used. The conversion function

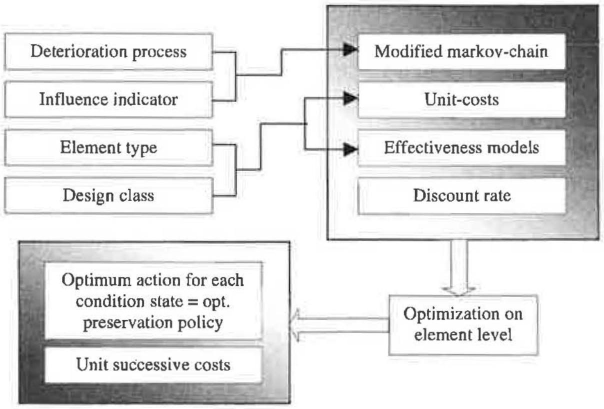


Figure 5: Optimization on the element level.

employed in KUBA-MS is piece-wise linear and needs two points for its definition: a threshold value, representing the amount of a segment up to which no action is triggered, and an upper limit, above which the whole segment is treated (see Figure 6). The system allows generation of an individual conversion function for every condition state of every deterioration process. This is necessary because condition states three and five, for example, cannot be treated identically.

Actions Due to Irregular Damages and Additional Elements

It has been noted that not all damages display the same characteristics with respect to element preservation actions. A distinction is made between "regular" and "irregular" damages. The conditions distinguishing regular damages are:

- Regularity of the deterioration process: These damages obey a continuous deterioration process, i.e., no sudden changes in the condition occur. All segments made of the same materials that are subjected to this deterioration process and exposed to the same environmental conditions behave more or less similarly.
- "Inspectability": In the deterioration process a number of condition states can be defined that differ noticeably. It is possible to recognize the condition states in a visual inspection.
- Relation to action types: A defined condition state can be linked to plausible action types. This relation defines the unit costs and the effectiveness of the action when applied to an element with a certain element type displaying the condition state.

Damages to the post-tensioned reinforcement of a structural element are a good example of these conditions not being fulfilled. A regular deterioration process cannot be observed because inspectability is not given and every action taken must be appropriate to the specific situation.

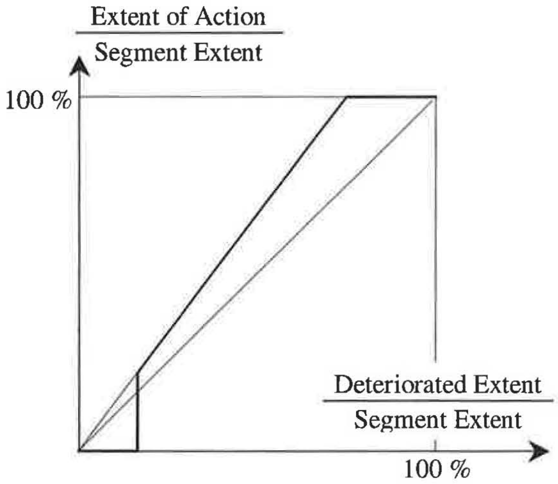


Figure 6: Conversion function for extent of action.

Each action due to an irregular damage has to be defined individually, together with the corresponding costs, based on a detailed description of the damage. The approach is reasonable because irregular damages are rare compared to regular damages.

Another exception is damages to parts of a structure that are usually not considered in the system, like foundations, anchorage or drainage systems. These "additional elements" are not included in the catalog of cost-relevant element types since preservation actions on them are very rare and require very specific planning. Cost estimates for these actions can be entered on the project level in order to take them into account in the optimization.

Generation of Preservation Projects Including Life-Cycle Costs

The process of project generation for entire structures constitutes the concrete realization of what is assumed in the calculation of the optimum preservation policy on the element level. The goal is that the generated preservation projects consist of optimum actions for each element. Consequently, a project is generated for a structure as soon as one of its segments requires an action according to the optimum preservation policy.

Figure 7 illustrates the generation of element actions in detail, with all relevant information. The inspected deterioration process and condition state determine which action is taken for a segment, including "do nothing" as an option. After calculating the extent of action, the cost can be calculated from the unit costs and the effect results from the effectiveness model.

The above results for all segments of a structure form a project, which is first of all characterized by the sum of the costs. These costs can be enhanced manually for actions due to irregular damages and for actions on additional elements. In this manner, the immediate costs for the agency can be obtained. In order to make a benefit-cost analysis, the costs for successive periods have to be generated as well. They can be computed by applying the unit successive costs obtained in the optimization on the element level to the condition of all segments after the completion of the project. They

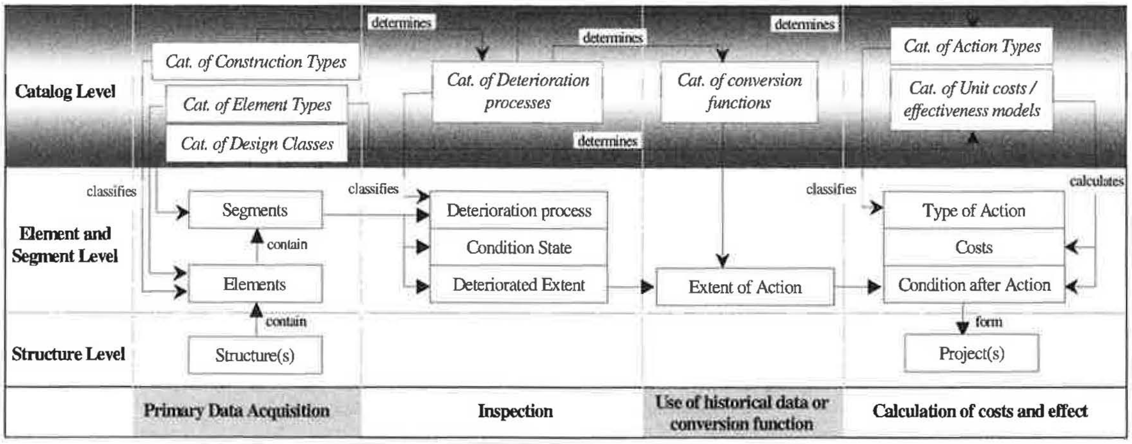


Figure 7: Generation of element actions and projects.

constitute the present value of all costs for future preservation actions up to infinity (excluding actions for irregular damages), under the condition that the optimum policy is pursued.

IMPROVEMENT MODEL

Preservation Versus Improvement

Separation of preservation and improvement actions is essential in the chosen approach. The model for planning preservation actions strictly presupposes that the functional properties of a structure (i.e., lane width, vertical clearance, weight limits, etc.) remain unchanged.

Improvement actions are distinguished from preservation actions in the following issues:

- Contrary to preservation actions, an automatic planning of improvement actions is hardly possible. Improvement actions are planned individually from case to case and strongly depend on local conditions, the structural system and other specific factors.
- Improvement actions imply a change of functional properties and result in a reduction of road-user costs, i.e., less traffic congestion or increased safety.
- Improvement actions are comparatively rare in the Swiss federal highway network; a manual input of the pertinent data is therefore reasonable.

If the system indicates a need for improvement, it is up to the user to decide in which period the improvement should be executed. For standard improvement actions, like bridge deck widening, the system provides unit costs; in other cases the user has to feed in cost data manually.

Road-User Benefit

Improvement actions can only be justified economically by a decrease in road-user costs, i.e., a reduction in traffic congestion. This decrease can be designated as user benefit. Compared to a project without the improvement, the alternative with the improvement is only profitable if the present value of user benefits is greater than the costs of the improvement. The calculation of user benefit is still a topic of investigation.

Generation of Improvement Projects

Improvement projects are triggered if the current functional properties do not meet the required standard. A deficiency is indicated and an improvement project can be defined. The user is prompted to enter a cost estimate for every individual case. Experience will show for which actions it is reasonable to include unit costs in the knowledge base in order to allow the user a semi-automatic calculation of the costs. The definition of the project is completed by adding road-user benefit.

Improvements are often executed in combination with preservation works. The improvement module therefore is designed as a "plug-in" to the preservation module. A generated preservation project can be cloned and enhanced by the costs of the improvement project, thus creating another project variant for the same structure.

OPTIMIZATION ON THE PROJECT LEVEL

Optimization on the project level aims to support the agency in deciding which projects to execute in the subsequent planning period. The horizon of the projects is two to five years (short-term planning). Faced with a large number of structures, the agency wants to know:

- which is the optimal option between minor rehabilitation, major rehabilitation and replacement, considering additional, scheduling constraints.
- which is the right moment to execute a major action, if the period for major actions is given and the moment can be determined free of additional constraints.

Additional constraints with regard to execution moment can include the need to group actions on predefined road (between two junctions), political decision, etc.

Road-User Costs

Actions on certain elements require that the traffic is restricted. Examples include repair or rehabilitation of pavement, the bridge deck, joints or retaining walls along the road. The hindering of the traffic can result in:

- delays due to speed reductions or congestion
- detours for all vehicles or the heavy traffic only
- an increase in accidents.

To calculate the monetary equivalents of these effects, mathematical models are applied that have been developed in the USA (*7,8*).

The agencies in Switzerland have no direct revenues from the traffic network, but are financed via gasoline taxes. Although the road-users thus indirectly pay for the roads, they cannot influence money allocation. As it became more and more difficult to justify the expenses for preservation, the agencies gained insight that the users are not particularly interested in long-term optimum preservation policy, but rather in the minimum number of traffic obstructions, since these impediments often result in direct losses for the users.

Although reliable estimates of user costs were not available, significant effort has been made to reduce them. On the one hand, actions on predefined road sections between two junctions are grouped in order to be executed simultaneously, thus achieving a reduction in user costs and the costs for traffic controls and installations. On the other hand, projects on road structures, pavements, electrical installations, as well as drainage systems and safety barriers, are regularly coordinated.

The management system accounts for the user costs directly on the project level and indirectly by enabling project grouping.

Cost-Benefit Analysis and Project Ranking

A cost-benefit analysis allows comparison of projects with regard to their life-cycle costs, including road user costs. It is executed in two steps:

1. Firstly, all project variants for a structure are compared. The variants can be common preservation works, improvements, replacement or "do-nothing" as a reference. Do-nothing means that for all periods only actions required to guarantee safety are executed.
2. In a second step the optimum variants for every structure are compared.

The mathematical model applied is the incremental cost-benefit analysis (*2*,*3*). The result is a ranking of structures according to a diminishing incremental benefit-cost ratio. Budget restrictions usually lead to the final choice of the projects to be executed in the concerned period.

Working Programs

The list of projects chosen in the cost-benefit analysis can be used to establish working programs. This allows optimization of resources for the management and execution of the projects.

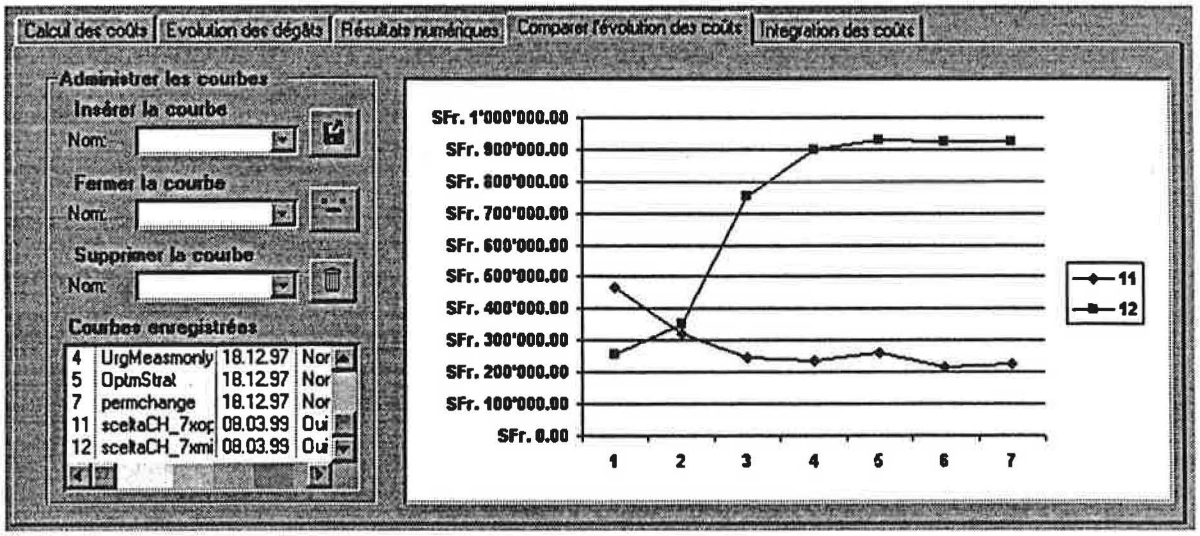
Clearly, some decisions are not motivated by economical criteria but rather by political aims. In these cases working programs can be changed manually and corresponding costs can be estimated.

STRATEGIC PLANNING ON THE NETWORK LEVEL

Optimization on the project level aims to assist the agency in short-term planning. It does not support study of the effect of the preservation policy on the network level in the medium- and long-term. The strategic planning module is designed as a management tool to obtain this information. Different preservation policies can be combined in order to account for budget restrictions. The effects on the total long-term preservation costs, as well as on the average condition, are illustrated graphically. This information is important in communicating the need to finance preservation activities to political authorities and to the public.

CURRENT STATUS OF IMPLEMENTATION—THE PROTOTYPE KUBA-MS-TICINO

In close collaboration with two cantons (Argovia and Ticino), on the basis of the master concept as well as of the intensive work of the highway agency of the canton Ticino, the prototype named KUBA-MS-Ticino was developed in 1997/98. Although this prototype



4	UrgMeasmonly	18.12.97	Nor
5	OptmStrat	18.12.97	Nor
7	permchange	18.12.97	Nor
11	sceltaCH_7xop	08.03.99	Oui
12	sceltaCH_7xmi	08.03.99	Oui

Figure 8: Example of two strategies calculated by prototype KUBS-MS-Ticino: (11) optimum policy during 7 periods and (12) execution of actions required to maintain safety and serviceability only.

does not include all the features foreseen in the master concept, its implementation offered important advantages:

- Future users of KUBA-MS have the opportunity to get familiar with the models contained in the management system.
- The data acquisition, which yields the data essential for the final version, can start earlier and thus enhance the value of the final version from its first use.
- First experience can be gained with the models, parameters can be calibrated and verification of the overall performance can be performed.

In the prototype KUBA-MS-Ticino certain features not foreseen in the master concept have been implemented:

- The users are allowed to edit most data contained in the knowledge base and to create their own parameter sets. Thus, the application can be a powerful tool for sensitivity analyses.
- In the calculation of life-cycle costs on the project level, the user can define the strategy that determines the successive costs by choosing the preservation policy (set of actions for each condition class and element) to be pursued in subsequent periods.
- In contrast with the master concept, the inspector does not determine a predominant deterioration process (where more than one deterioration process is acting on a segment) in order to assign a segment only one condition state of a single deterioration process. The prototype allows collection of a detailed deterioration profile describing the condition of a segment with all present condition states of all identified deterioration processes. In a simple algorithm the program determines the predominant deterioration process itself.

CONCLUSION AND OUTLOOK

The growing demands on the management of road structures have led to the development of a management system in Switzerland. Although basically similar objectives as for comparable systems have been defined, specific conditions and extensive investigations have led to partly different approaches.

Three years after concept approval a prototype was realized, which comprises most of the features foreseen in the concept. The prototype was tested by several highway agencies in Switzerland during a few months and the results were analyzed systematically. A wide range of user demands was revealed, giving few impulses to the ongoing developments. The close collaboration with the user makes the development a challenging job, despite many organizational obstacles.

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