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SETTING PRIORITIES FOR MANAGEMENT OF HYDRAULIC STRUCTURES IN MOUNTAINOUS CATCHMENTS

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Trained citizen-volunteers can support civil protection and technical services to inspect the functional status of hydraulic structures. Volunteers carry out first level inspections of bridges and check dams by compiling standardised forms while looking the following parameters: A) Condition of the structure, B) Level of obstruction at the structure and C) Presence of protection works and erosion level in the stream bank. The aim of this work is to support technicians on the evaluation of volunteers' inspections. The output are indexes at parameter level on the functional status of the inspected structure. To that end, this research presents the definition and design of a decision support methodology to be implemented as web-based tool. Technicians evaluate volunteers' inspections at parameter level. First, technicians assign weights to the components questions of the inspection form assisted by the analytical hierarchy process (AHP). From available volunteers' inspections, volunteer ratings are systematically converted into rating scores using fuzzy logic theory. Finally, we used the multi-criteria TOPSIS method to aggregate the weighted-rating scores into indexes for the functional status of the structure. Based on those indexes, technicians can set priorities on the management of hydraulic structures. We established the user requirements based on a case study in the Fella Basin, Friuli-Venezia-Giulia region, Italy. Future research will test the conceptual design with actual technicians of the region for improving the methodology and the functional requirements of the web-based tool.

INTRODUCTION

Despite the relevance for the frequent inspection of hydraulic structures in mountain catchments, technical inspections have limited frequency and coverage [1]. Some reasons for those limitations are the extensive number of structures in many regions and the limited financial and human resources [2]. Trained citizen-volunteers could support civil protection and technical services to inspect the functional status of hydraulic structures, hereafter referred as first level inspections.

However, first level inspections should support decisions about obstructions or pre-screen potential problems without replacing advanced assessment procedures when they are needed. Moreover, technicians should evaluate volunteers' inspections for getting indication at parameter level, on the functional status of the inspected structures. To that end, we propose a decision support methodology that technicians can use as web-based tool to evaluate available volunteers' inspections.

The decision support methodology follows an user-centered design approach [3]. Such approach entails three main phases: (1) analysis of user requirements; (2) design and implementation; and (3) evaluation of the decision support tool. This paper focuses on the definition and design of the decision support tool, as they are carried out within the first two phases.

METHODOLOGY

Methods comprise the analysis of user requirements in the framework of inspections campaigns promoted by Civil Protection and local authorities in Friuli Venezia Giulia (FVG). Initial requirements were identified via semi-structured interviews, meetings with stakeholders and a data collection exercise in the Fella Basin to evaluate quality of data collected with volunteers.

Available knowledge and resources for management of hydraulic structures

On one side, there are some initiatives to support exchange of information between civil protection and technical services at regional level. That is a geo-information system called SIDS (an acronym that literally stands for Sistema Informativo Territoriale per la Difesa del Suolo, i.e. Territorial Informative System for the Soil Defense), which is used by technical services to validate hydro-meteorological events that are reported to the Civil protection. The system also allows technical and Civil Protection services to share available databases regarding hydraulic infrastructure and protection works.

On the other side, there are inspections campaigns with citizen-volunteer groups promoted by Civil Protection and local authorities of FVG. In those campaigns, trained-citizen volunteers survey the territory and relevant structures at municipality level for hydro meteorological hazards. However, there is a need for standard volunteer inspections and for enhanced survey procedures to support preventive maintenance of hydraulic structures.

User requirements for the first level inspection of hydraulic structures

We defined user requirements while designing the forms for first level inspections of hydraulic structures with citizen-volunteers of Civil Protection. The layout of the inspection forms was established with four risk managers of Civil Protection, Geological Survey and Forestry Service of FVG. Overall, the inspection forms focus on the functional status of bridges and check dams due to their relevance for water-sediment processes in mountain catchments.

Therefore, we refer to functional status by looking at the physical conditions or susceptibility of the structure that may affect the function type for which it was designed or built [4]. To that end, inspection forms should be pre-compiled with location, simplified identification of the function and structure type. For bridges, we considered bridges or culverts while check dams include consolidation and open check dams.

We evaluate functional status by asking volunteers to observe and report questions regarding three parameters: (A) Condition of the structure; (B) Level of obstruction at the structure; and (C) Presence of protection works and erosion level in the stream bank. Besides the section for the functional status, we included other sections about the conditions to carry out

the inspection and the presence of anthropic elements. Those sections become relevant for the evaluation of inspections, when different volunteers inspect the structures at different times.

Then, volunteers are asked to observe and fill the inspection form, whose questions are also accompanied by an opportune rating scale^{1,2}. When water or sediment does not allow the inspection, reported condition can be rated with an unspecified option.

Finally, we carried out a training session and data collection exercise to evaluate the precision, accuracy and completeness of data collected with volunteers [5]. From that exercise, we identified important elements to use volunteers' inspections for decision-making regarding preventive maintenance of structures.

The considerations for decision-making account for the aggregation of rating scales to handle the subjectivity of volunteer ratings. That is the aggregation of rating classes from the description coming along the classes (e.g. aggregation from low-to-very-low rating classes). Considerations for decision-making also account for the calculation of a completeness ratio, i.e. ratio Question/Parameter, anytime volunteers use unspecified options in their inspections.

DECISION SUPPORT METHODOLOGY TO EVALUATE FIRST LEVEL INSPECTIONS

Results from the design phase comprise the workflow to evaluate volunteers' inspections, system and functional requirements for the implementation of the decision support methodology as web-based tool.

Workflow for the evaluation of volunteer inspections

The methodology here presented focuses on the evaluation of volunteers' inspections. This study adapted the framework for asset management of road structures [6]. Then, the process starts from first level inspections that volunteers have submitted to the Civil Protection. In Figure 1, the evaluation process comprise the steps from the weights up to the colour mapping of the indexes for functional status.

¹ https://horatius.irpi.pd.cnr.it/changes-fella/Fella_iframes/pdf/Rapporto/OnlineAppendix_1_Bridges.pdf

² https://horatius.irpi.pd.cnr.it/changes-fella/Fella_iframes/pdf/Rapporto/OnlineAppendix_2_Checkdams.pdf

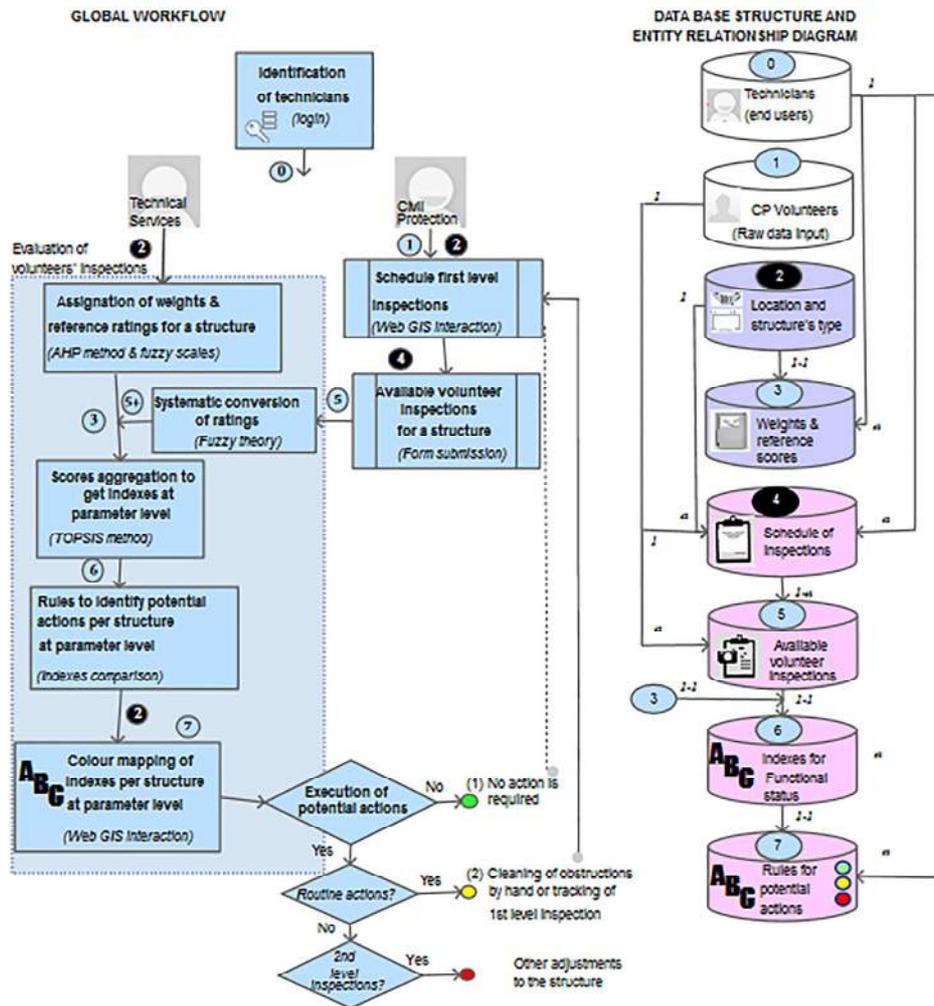


Figure 1. Global workflow and entity relationship diagram for the database structure

System requirements for the evaluation of reports.

We chose a web-based environment to support data sharing and accessibility between different technical agencies. Then, the system requirements to implement the decision support methodology are based on a client-server architecture (Figure 2). As a result, the web-based tool here presented has three main components: 1) Knowledge base; 2) Graphical user interface and 3) Database management system.

The knowledge base comprises of the methods implemented along the workflow to assist technicians on the evaluation of volunteers' inspections. The graphical user interface is still a prototype and it has been kept as simple as possible to evaluate the decision-making methods with actual technicians of the FVG.

Finally, we present the entity-relationship diagram for the database management system in Figure 1, together with the workflow. That is to illustrate the data flow at each step: (1) login data for the technicians (end-users); (2) identification of volunteers, (3) Data on the location and type of structure; (3) Sets of weights and reference rating scores for a given structure; (4)

Schedule of structures assigned for volunteers' inspection; (5) Available volunteers' inspections; (5) Indexes for the functional status of the inspected structure and (6) Rules to identify potential actions per structure at parameter level.

On one side, spatial data is limited to the point entity, i.e. structure location. Then, the location of the structures is always known and is static data. Non-spatial data includes two data types. The static data comprises the set of weights and reference ratings for a given structure. The dynamic one includes volunteers' rating scores coming from available first level inspections; the calculated indexes for the functional status; and the rules for potential actions. However, we coloured the structure location according to the calculated indexes for the functional status.

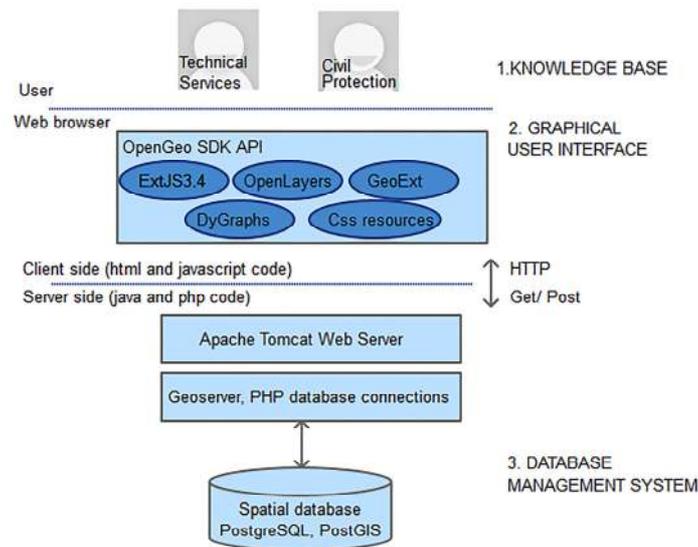


Figure 2. Client-server architecture for the prototype web tool

Functional requirements of the web-based tool as steps in the workflow process

- Set of weights and reference scores to evaluate the status of the inspected structure:** Technicians should carry out pair-wise comparisons to define the weights for the component questions at parameter level (Figure 3). Then, we used the AHP process to define the weights based on the pair-wise comparison of technicians [7]. In addition, we set reference ratings for the best and worst case on each component question, according to the maximum and minimum classes in the rating scales.

Define weights for component aspects in Parameter A

Definition of weights

Based on the aspects to inspect for each parameter now the goal of the stage is to define the weights for each component aspect. You can make any adjustments you want to the weights assigned by comparing the relative importance among the aspects to take into account.

1. Select the aspects to consider: 2. Compare their relative importance: 3. Define their weights:

Use the scale to adjust the relative importance of all statements for the best functionality of Parameter

A) Condition of the structure

A6) Status of the protection for scouring at the downstream bottom of the check dam	is equally important as	A1) Deviation of the stream flow
A3) Visibility of the basis of the structure	is equally important as	A1) Deviation of the stream flow
A2) Status of the check dam	is equally important as	A1) Deviation of the stream flow
A4) Status of the protection for scouring at the downstream bottom of the check dam	is equally important as	A2) Status of the check dam
A2) Visibility of the basis of the structure	is equally important as	A2) Status of the check dam
A4) Status of the protection for scouring at the downstream bottom of the check dam	is equally important as	A3) Visibility of the basis of the structure

Previous Next
Close

Figure 3. Example of a pair-wise comparison for the component questions in A parameter. Check dams' inspection.

- Systematic conversion of volunteer ratings into rating scores:** Since the rating scales are expressed in linguistic terms, we assign each class description with a fuzzy term [8]. Then, rating scores varying in the interval [0,1] from minimum to maximum concerns in the functional status. In addition, all component questions included the unspecified option "Could not be answered", specifically thought for the case in which the structure can't be inspected due to location condition. We refer to those cases as "unspecified answers" and assign to them medium concern rating score.

However, a completeness percentage (Question/Parameter) is calculated at parameter level, anytime volunteers' inspections use unspecified options. The completeness percentage represents the number of questions without "unspecified answers" above total questions per parameter (%A, %B and %C).

- Aggregation of rating scores to get functional indexes for the inspected structure:** The index for the functional status is the combination of volunteers' rating scores, which are aggregated using TOPSIS method [9]. Technicians have access to both weighted and un-weighted rating scores to distinguish the weights' effect on the index definition (Figure 4).
- Rules to identify potential actions for the inspected structure:** We assist the definition of the rules by calculating indexes of the functional status for all possible combination of rating scores. The calculation use the same set of weights that were assigned for the given structure. Figure 5 illustrates the systematic comparison of indexes to support technicians on the rules definition. Then, technicians can set rules at parameter level, considering the following aspects: (1) worst rating score for any question; (2) Worst rating score for the maximum weighted question; and (3) a minimum threshold for the index on the functional status.

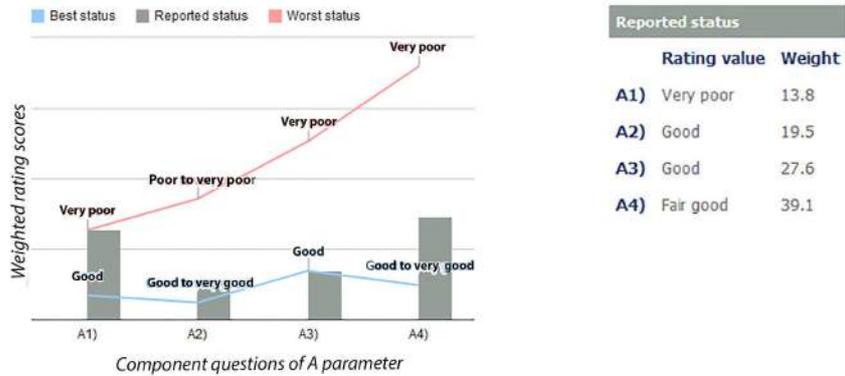


Figure 4. Bar chart examples for weighted and un-weighted rating scores.

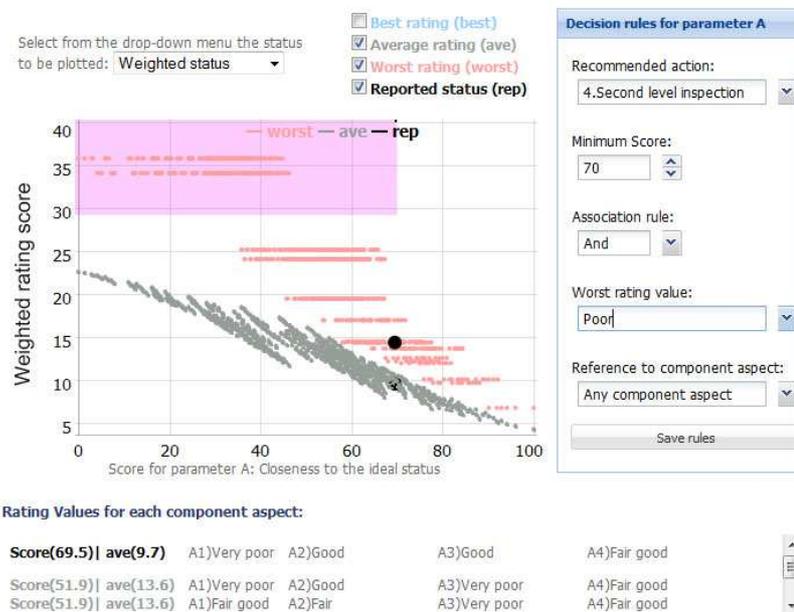


Figure 5. Systematic comparison of functional indexes

- Colour mapping of indexes for the functional status at parameter level according to the rules definition:** Technicians can visualize the outcomes of the rule definition by looking at the colour assigned to the structures according to the rules definition. The process allows the colour mapping of the structure location while distinguishing between three possible actions: (1) No action is required (green); (2) routine cleaning or tracking of first level inspections (yellow); and (3) second level inspection (red).

CONCLUSIONS

- Since very preliminary stages, the stakeholder has been involved in the design of the decision support methodology here presented.
- Technicians can use the methodology to set priorities for the management of structures based on their functional status.
- We used fuzzy logic theory to handle the subjectivity of volunteers' ratings by aggregating the rating classes from the pre-required ranges in precision (e.g. from very-low-to-low).
- The current approach is currently under implementation and will be tested with actual technicians of Friuli Venezia Giulia region.

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