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Review

A systematic review of application of multi-criteria decision analysis for aging-dam management

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ABSTRACT

Decisions for aging-dam management requires a transparent process to prevent the dam failure, thus to avoid severe consequences in socio-economic and environmental terms. Multiple criteria analysis arose to model complex problems like this. This paper reviews specific problems, applications and *Multi-Criteria Decision Making* techniques for dam management. Multi-Attribute Decision Making techniques had a major presence under the single approach, specially the Analytic Hierarchy Process, and its combination with Technique for Order of Preference by Similarity to Ideal Solution was prominent under the hybrid approach; while a high variety of complementary techniques was identified. A growing hybridization and fuzzification are the two most relevant trends observed. The integration of stakeholders within the decision making process and the inclusion of trade-offs and interactions between components within the evaluation model must receive a deeper exploration. Despite the progressive consolidation of *Multi-Criteria Decision Making* in dam management, further research is required to differentiate between rational and intuitive decision processes. Additionally, the need to address benefits, opportunities, costs and risks related to repair, upgrading or removal measures in aging dams suggests the Analytic Network Process, not yet explored under this approach, as an interesting path worth investigating.

Contents

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1. Introduction

It is estimated that by 2050 the population will have increased by 130 million, much of the increase being located downstream from reservoirs contained by dams that are aging and presenting therefore significant potential risk (Ferre et al., 2014).

Today, owners of dams face a significant challenge in allocating limited financial, human and material resources to ensure adequate operating conditions in old dams. The absence of proper investment in conservation of the dam condemns it to the very likely event of failure, with particularly severe consequences in socio-economic, environmental and heritage terms (Donnelly and Morgenroth, 2005). It is necessary, therefore, to provide a transparent decision process so as to facilitate public participation in decision-making on dams that are deteriorated or aging (Pittock and Hartmann, 2011). Assessing the status of an aging dam requires the bringing together of quantitative and qualitative information, since the factors that determine the state of the dam (structural, geological, environmental, etc.) are deterministic, stochastic or fuzzy in nature (Su et al., 2006).

Deterioration may appear throughout the whole dam life cycle, from its construction phase to its completion, demolition or abandonment phase. Ageing can be defined as the deterioration process that occurs more than five years after the beginning of the operation phase, so that deterioration occurring before that time is attributed to inadequacy of design, construction or operation. Even beyond that time, dam ageing can be considered as a class of deterioration associated with time-related changes in the properties of the materials of which the structure and its foundation are constructed. Besides the type of structure, other factors significant to the ageing problems are the environmental conditions, dimensions, design and construction standards, nature of operation and maintenance and congenital and early age deterioration of structures (International Commission on Large Dams and ICOLD, 1994).

The problem of deterioration through aging is one that also applies to the reservoir contained by the dam, where environmental degradation may be observed (within the short and medium terms of the life of the structure, <50 years), in the form of: (i) alterations in the flow system, (ii) loss of longitudinal and floodplain connectivity, (iii) altered sediment system, (iv) changes in the composition of the substrate and, (v) degradation of the downstream channel. The environmentally-related problems in the long term (>50 years) of the dam-reservoir system is, still today, even less well-known; therefore, new decision-making processes must be developed for the management of these systems in a situation of deterioration through aging (Juracek, 2014).

There is a close connection between Climate Change and managing the operation of ageing dams. Hydrological changes brought about by the former lead to the need to reassess the safety conditions of dams in general, but even more so in older dams; many of them already considered unsafe in periods before the onset of Climate Change. There are a great number of existing dams, at an advanced stage of deterioration, that are especially vulnerable to extreme natural phenomena linked to Climate Change. The determination of the vulnerability index as a means of diagnosing the real state of the dam serves as a clear support to decision-making on its conservation, maintenance and rehabilitation (Bouzelha et al., 2012).

Generally, decision-making processes in dam management use a combination of decision bases ranging from technical codes and standards-based ways of assessing alternatives to values-based assessments based on company or wider societal values and stakeholder expectations and perceptions. The inclusion of social sustainability criteria and factors within the evaluation model to be developed must be guaranteed by addressing social and cultural impacts on human populations derived from the decisions undertaken on an ageing dam during its operational phase. The decision-maker must weigh and balance community, owner and other stakeholder interests and make all necessary value judgments, including those needed to weigh different types of risks: monetary loss, environmental degradation, etc. In parallel, political risks and resources allocation among competing societal needs must be considered. These are all subjective tasks to which knowledge-based disciplines can give little assistance (Risk Assessment in Dam Safety Management (2005)).

The inclusion of social sustainability criteria and factors within the evaluation model must be guaranteed by addressing the social and cultural impacts derived from the decisions undertaken on an ageing dam during its operational phase (Sierra et al., 2016). Essentially, sustainability applied to aging-dam management must be understood as the reconciliation of the economic, environmental and social aspects intrinsically related to complex decisions (Torres-Machi et al., 2014). Ultimately, from a cognitive perspective, the adequate approach to aging-dam management must be to improve knowledge on the decision-making process and to make it possible for the stakeholders participating in the resolution process and its integrated systems to learn from the experience (Yepes et al., 2015; Moreno-Jiménez et al., 2012, 2014).

Decision-making in water resources management is driven by multiple objectives. Multi-Criteria Decision Analysis (MCDA) has been used in areas such as watershed management, groundwater management, selection of hydraulic infrastructure (mainly urban water supply), watershed management, water policy planning and management, water quality management and the management of protected coastal areas (Hajkowicz and Collins, 2007). Over a long time scale, with a variety of decision-makers, the use of MCDA reveals itself to be more suitable compared with other techniques usual in water resources management such as multi- or mono-objective optimization or cost benefit analysis (CBA) (Scholten et al., 2014). MCDA provides an excellent support to prioritize rehabilitation activities in ageing dams. Therefore, this review analyzes the application of Multi-Criteria Decision Making (MCDM) methods and techniques to the comprehensive management of dams throughout the whole infrastructure lifecycle and identifies the specific treatment given to these methods in its application to ageing dams during its operational phase.

2. Search strategy and methodology

The purpose of the literature review was to identify trends and gaps in research and to propitiate further progress upon the foundation developed by others. A systematic, objective review