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OPTIMISING MULTI-CRITERIA ASSESSMENT TO ACHIEVE EQUITABLE STAKEHOLDER OUTCOMES IN WSUD SCHEMES

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Introduction

A new optimisation-visual analytics decision-support framework for complex environmental management problems involving multiple stakeholders is presented. The framework adds an optimisation approach to multi-criteria analysis techniques that are typically used in water sensitive urban design (WSUD) stakeholder consultation practice. By using the framework, decision makers are presented with the optimal combinations of projects that achieve efficient outcomes in terms of multiple benefits and costs for each stakeholder. The optimal portfolios can act as a performance benchmark when selecting projects to be funded. In addition, by using a visual analytics software package, stakeholders can visualise and compare how the preferred portfolios of others perform against their own values and interests. The framework was applied to a 16-objective multi-stakeholder WSUD project selection problem, using real-world multi-criteria analysis data derived through stakeholder consultation by consultants.

Multi-stakeholder optimisation

Optimisation is a computational problem solving and decision support approach that attempts to find the best solutions to a complex problem according to some pre-defined objectives. In portfolio optimisation approaches, solutions are typically identified using an optimisation algorithm, and are the combinations of projects ('portfolios') that provide the best possible benefits at minimal cost. The optimisation problem to be solved has generally been represented by a single formulation, including all decision variable options, up to 3 or 4 objectives, and constraints considered to be relevant [1,2,3]. However, this is not possible where there are multiple stakeholders, each bringing their own values and interests that are represented as objectives.

An example of this is the integrated management of a river system and its catchment. In this case, the objectives of stakeholders managing separate sub-areas of the catchment would most likely be different from each other, and different from those of stakeholders concerned with managing the catchment as a whole. In this case, optimising portfolios of projects for multiple stakeholders requires a new approach, as described in the following section.

Methodology

The new proposed multi-stakeholder optimisation framework consists of four steps:

1. Multicriteria assessment – identify and evaluate individual projects
2. Multi-stakeholder portfolio optimisation – identify the optimal portfolios of projects for each stakeholder, and jointly-optimal portfolios
3. Visual analysis – visualise the multiobjective performance trade-offs of jointly-optimal portfolios
4. Selection and negotiation – several portfolios are selected and presented to decision-makers who then select one of them.

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In the first step, a typical multicriteria assessment is carried out by consultants with representatives from each of the stakeholder bodies. Numerous potential projects are identified, then each is evaluated against multiple objectives. The objectives should represent the values of the individual stakeholders. For example, a local council may value the stormwater harvesting, water quality improvement and amenity benefits of projects within its boundaries. The lifecycle costs and interactions between projects (e.g. potential downstream effects) are also evaluated.

In the second step, the stormwater management problem is represented as a series of smaller, interconnected optimisation problems, reflecting individual stakeholder interests. These optimisation problems are each solved using a multiobjective optimisation algorithm, to produce optimal portfolios for each stakeholder. The optimal portfolios maximise trade-offs between multiple benefits accruing to the individual councils including stormwater harvesting and amenity benefits, and the total catchment benefits including water quality improvement at the catchment outlet. The optimal portfolios that are sub-optimal for one or more stakeholders are eliminated, leaving only the jointly-optimal portfolios for further consideration.

In the third step, the trade-offs between objectives of the jointly-optimal portfolios are presented in a 'multi-stakeholder trade-off space'. This involves a visual analytics software package, which can present large data sets in a form that can be rapidly analysed. The fourth step, involves stakeholders making a selection from among the jointly-optimal portfolios, using the visual analytics package to do so.

Case study

The framework was applied to a case study multi-stakeholder catchment management problem (Figure 1). The project involved four stakeholders (three local councils and a catchment management authority (CMA)) each with four values or interests to be formulated as optimization objectives. 70 biofilters, swales and wetland projects were identified and evaluated in a multicriteria assessment undertaken by consultants and the stakeholders. The remaining steps of the framework were carried out by analysts (the authors). Four optimisation problems were solved, each representing the available projects and values of one stakeholder. The decision variables, 16 objectives and constraints for each problem are shown in Table 1. Objectives are in order of priority assumed for each stakeholder. It was assumed the CMA would fund capital expenses (CAPEX), and councils fund operating expenses (OPEX) of projects.

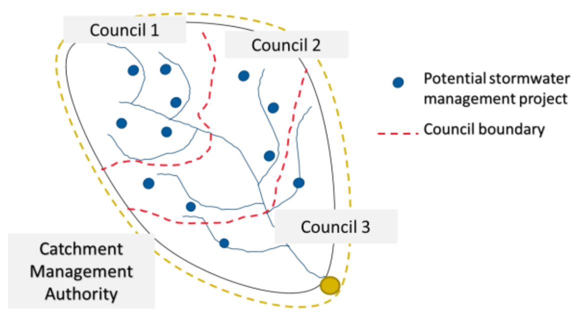

Figure 1. Portfolio of stormwater management projects

Table 1. Optimisation problem formulations

Problem formulation	Decision variables	Objectives	Constraints
CMA	All projects	$CAPEX_{CMA}$ $TNRed_{CMA}$ SWH_{CMA} $GREEN_{CMA}$	≤ 20 projects
Coun. 1	Coun. 1 projects	$OPEX_1$ SWH_1 $GREEN_1$ $TNRed_1$	≤ 7 projects
Coun. 2	Coun. 2 projects	$OPEX_2$ $GREEN_2$ SWH_2 $TNRed_2$	≤ 7 projects
Coun. 3	Coun. 3 projects	$OPEX_3$ SWH_3 $GREEN_3$ $TNRed_3$	≤ 7 projects

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Note: CAPEX = capital expenditure, OPEX = operating expenditure, SWH = total volume of harvested stormwater, TNRed = total nitrogen reduction, GREEN = amenity 'green' score.

Lifecycle costs for each project were calculated based on objective functions and data from [1, 4]. The water quality improvement indicator, total nitrogen (TN) reduction, was evaluated using eWater MUSIC based on the project type and surface area dimensions. The amenity value for each project was based on an aggregate of three indicators for each project, which were evaluated by council staff. The total volume of harvested stormwater was estimated by consultants and council staff.

The Pareto Ant Colony Optimization Algorithm [5] was used in this study. This identified 2,537 portfolios containing optimal sub-portfolios that were solutions of the four problem formulations. The jointly-optimal solutions represented 125 of the optimal portfolios that consisted of an optimal sub-portfolio from every stakeholder. The jointly-optimal portfolios were visualised in DiscoveryDV software for further analysis.

Results

The jointly-optimal portfolios were presented in a multi-stakeholder trade-off space using the visual analytics software. Portfolios of projects that would be preferred by each stakeholder were selected, and compared to see how equitably the portfolios shared capital expenses (CAPEX) (Figure 2).

The selected portfolios were analysed based on their performance in each stakeholder's value set of objectives, to identify viable portfolios that can be adopted or used as a benchmark for further negotiation between stakeholders. Table 2 shows an example evaluation matrix, where each stakeholder evaluates the solutions selected by others, against their set of values, to identify potentially viable portfolios.

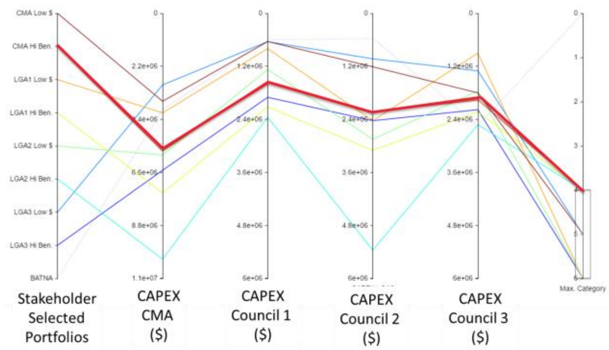

Figure 2. CAPEX distribution for selected portfolios

Table 2. Example evaluation matrix for selected jointly-optimal portfolios

	Portfolio CMA	Portfolio C1	Portfolio C2	Portfolio C3
CMA	Yes	No	Maybe	Yes
Coun. 1	Yes	Yes	Maybe	Yes
Coun. 2	Maybe	Yes	Yes	No
Coun. 3	Yes	Yes	Yes	Yes
Viable?	Maybe	No	Maybe	No

Conclusion

A new optimisation method for selecting project portfolios for management problems involving multiple stakeholders was presented. The jointly-optimal portfolios for multiple stakeholders were determined using an optimisation algorithm, and were explored, analysed and selected with the aid of a visual analytics package. The approached identified potentially equitable portfolios of biofilters, swales, and wetlands projects, that that achieve efficient outcomes in terms of stormwater harvesting, water quality, and amenity benefits and costs for each stakeholder

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