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Artificial intelligence techniques for flood risk management in urban environments

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Abstract

Urban flooding is estimated to cause £270 million pounds worth of damage each year in England and Wales alone. There has, therefore, been a clear need to develop improved methods of identifying intervention strategies to reduce flood risk in urban environments. This paper describes ground-work performed towards evaluating the relative suitability of several algorithms applied to multi-objective optimisation of flood risk intervention strategies in an urban drainage network. An effective methodology is described for reducing an array of return period/duration rainfall files to a minimum, and it is described how this methodology makes possible comparisons of optimisation algorithms. This work has been undertaken as part of a STREAM-IDC EngD project which is a collaborative effort between the University of Exeter, and HR Wallingford.

Keywords: Innovation; Technology; Multi-objective; Optimisation; Optimization; Drainage; Floods; Flooding

1. Introduction

Urban flooding (usually caused by rainfall overwhelming drainage systems) is a serious problem which is estimated to cost £270 million per year in England and Wales with 80,000 homes at risk according to a report by the Parliamentary Office of Science and Technology (2007). In addition to water damage to properties and businesses there is a significant humanitarian cost in terms of both physical and mental health issues as a result of

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disease, forced relocation (temporary or otherwise) and property damage. Looking at these facts and estimates it is clear that there has been a need to develop improved methods for identifying the most cost-effective intervention strategies that best mitigate damage from flooding events. HR Wallingford, in partnership with the department of trade and industry (now the department for business, innovation and skills) , has recently developed a project titled DTI-SAM (Department of Trade and Industry, System-based Analysis and Management of urban flood risks) (see the reports by HR Wallingford (2009) and Kellagher et al. (2009)). In the DTI-SAM project, a risk-based methodology was produced along with an accompanying toolset for assessing the flood damage likely within a given area utilizing a given drainage network, an Infoworks CS model and a rapid flood spreading model developed in-house, described in Lhomme et al. (2008). The flood damage is assessed in terms of expected annual damage (EAD) which is a cost-based measurement representing the expected average infrastructure costs as a result of flooding each year. This toolset has been modified in this work to allow it to be easily run in an automated fashion, and re-branded as ADAPT (A Drainage Analysis and Planning Tool). As part of this modification, the simulation algorithm and the user interface were separated, and a new user interface developed that combines control of the simulation with control of the optimisation algorithms. In addition to this, a simplified costing model has been developed to estimate the cost (in terms of contractor charges and material expenses) of making a given set of alterations to a drainage system. The EAD and the Cost model are then to be used in a multi-objective algorithm, which aims to balance the two factors and present a pareto front, as originally described in Pareto (1896), of potential solutions. This Pareto front can then be utilised by a trained Engineer to guide decision making.

The selected optimisation methodology will be based on a multi-objective genetic algorithm, the non-dominated sorting genetic algorithm, version two (NSGA-2) as described by Deb et al. (2002). The new methodology incorporates the option of using artificial neural network meta-models in a similar fashion to Behzadian et al. (2009), or the learnable evolution model for multi-objective optimisation (LEMMO) studied in Jourdan et al. (2005).

Estimating the cost of changes to the drainage network is a straightforward process, completed practically instantaneously on any modern computer. The process of estimating EAD, however, is extremely computationally intensive when using all possible rainfall data, i.e., return periods and durations (taking around 5 hours for a full run). A full evaluation would lead to an unfeasibly lengthy run-time if a full optimisation utilizing all this data were to be attempted. Therefore in order to make the use of this algorithm feasible, the possibility of reducing the amount of rainfall data utilised have been investigated. This was done with the aim of having the least possible impact on the accuracy of the EAD figure generated (in particular, the relative differences between EAD figures must be maintained, in order for the multi-objective algorithm to function correctly). Once this process is complete, the user will be able to gain an estimation of the Pareto front with reasonable accuracy. This, in turn, will allow comparing optimisation algorithm options in terms of how quickly they achieve a reasonable approximation of the Pareto front.

Nomenclature

ADAPT	A Drainage Analysis and Planning Tool
DTI-SAM	Department of Trade and Industry, System-based Analysis and Management of flood risks
EAD	Expected Annual Damage
LEMMO	Learnable Evolution Model for Multi-objective Optimisation
NSGA-2	Non-dominated Sorting Genetic Algorithm version 2
RFSM	Rapid Flood Spreading Model

2. Methodology

This section describes the methodology of the work being performed, starting with a definition of the problem that is being optimised, followed by the calculation of EAD, a description of the cost calculation, and finally descriptions of the optimisation algorithms that have been implemented and will be tested using the methodology outlined in this paper.