Chapter 4
Artificial Intelligence and Optimisation Techniques for Risk Reduction in Civil Engineering

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ABSTRACT

Artificial intelligence techniques are at the centre of a major shift in business today. They have a very broad array of applications within businesses, including that of optimisation for risk reduction in civil engineering projects. This is an active area of research, which has started to see real-world applications over the last few decades. It is still hindered by the extreme complexity of civil engineering problems and the computing power necessary to tackle these, but the economic and other benefits of these emerging technologies are too important to ignore. With that in mind, this chapter reviews the current state of research and real-world practice of optimisation techniques and artificial intelligence in risk reduction in this field. It also examines related promising techniques and their future potential.

INTRODUCTION

Civil engineering comprises the design, construction, operation, and maintenance of buildings and infrastructures including a variety of works such as residence, bridges, and roads (Zavala et al., 2014). Since the second World War, with the rapid advances made in computational methods, optimisation techniques based on mathematical programming have been increasingly deployed in the field of civil engineering (Topping, 1983). Optimisation refers to acquiring the best outcome under specific conditions (Rajput & Datta, 2019), and optimization problems are evident in many disciplines, including operations research, computing, engineering and economics. Optimisation techniques consist of a powerful set of tools that can be deployed to help the effective management of a company's resources, and can be seen as an artificial intelligence (AI) tool. Kolter and Procaccia (2017) noted that "one of the most significant

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trends in AI in the past 15 years has been the integration of optimization methods throughout the field" (p.5). More specifically, in the field of civil engineering, optimisation can be executed in each step of a project life cycle, from design and construction to operation and maintenance, but can also be applied more generally to risk estimation and reduction (Dede et al., 2019; Mei & Wang, 2021).

Optimisation algorithms can be used to identify solutions to correctly formulated optimisation problems. This requires the formulation of an equation, or objective function, which calculates a measure of performance. Variables in the problem being optimised can then be represented as combinations of parameters for this function. For example, a problem such as drainage network optimisation can be represented as an optimisation problem by the use of an equation for calculating the cost of making changes to an existing drainage network. The parameters for this equation involve a mobilization cost (M) representing an initial cost of making change. Additionally, a combination of a cost for each pipe altered (I), the length of pipe requiring alteration (L) and the cost of purchasing pipes of a particular cross-section (c). Finally, storage tank alteration costs (S), area of the storage tank (a) and a base cost (b) as shown in equation 1 (Sayers, 2015).

$$Cost = M + \left(\sum_{i=0}^{n} I \times L_i \times c_i\right) + \left(\sum_{j=0}^{n} S \times a_j + b\right) + \left(\sum_{k=0}^{n} o_k\right) \tag{1}$$

Importantly for most algorithms to function well, this objective function must return values which are differentiable and represent the problem space well. This means that identifying a suitable objective function is in many cases one of the most complex parts of formulating a problem as an optimisation problem. Making this more challenging, is the fact that in most optimisation algorithms this objective function will be called a very high number of times, as different solutions are tested through the optimisation process. This is because of an effect known as "combinatorial explosion", where the number of parameters has an polynomial effect upon the size of the search space (dramatically increasing it in response to a small increase in parameters, or parameter values). Because of this, if an objective function takes even a few seconds to complete, this will result in extremely time-consuming algorithm runs when trying to be sure to undertake a reasonable exploration of the search space. Unfortunately, the majority of civil engineering optimisation problems are extremely complex and sometimes multi-objective optimisation problems, meaning they are generally computationally intractable, as exhaustive, or even mostly exhaustive, searches. Because of this, optimisation algorithms for these applications are generally non-deterministic, and are based around the use of heuristics. These heuristics allow them to be applied to problems where an exhaustive search for solutions with a computer is impractical, and still identify a reasonable solution. If this problem is even more pressing, then meta-heuristics and artificial intelligence techniques can be used to further alleviate this, such as machine learning regressors trained to approximate the above equation without the need to complete the processing associated with a full evaluation of this equation.

The objectives of this chapter are to first present a review of academic literature on optimisation techniques, including an outline of optimisation techniques and how they work and may be applied to engineering related problems. This is followed by an assessment of some examples of risk reduction and risk assessment optimisation in civil engineering, and a discussion of emerging issues. Finally, the concluding section offers some reflection on research directions, prospects for the field, and the practicalities of applications.