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Solid waste planning under uncertainty using evolutionary simulation-optimization

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Abstract

A key aspect of effective public planning design is to minimize the impact of negative outcomes that can arise from the violation of pre-established system constraint criteria. These planning situations can be especially complicated when several components within the studied system are either unknown or contain considerable stochastic uncertainty. In this paper, the concept of outcome minimization through the use of penalty functions is combined with grey programming (GP) into an evolutionary simulation-optimization (ESO) procedure in order to solve solid waste management problems containing significant sources of uncertainty. By employing outcome minimization concurrently with GP and ESO, it can be shown that plans that meet, or come close to meeting, required system criteria can be efficiently created. The efficacy of the procedure is demonstrated through its application to a solid waste planning case from the Municipality of Hamilton–Wentworth in the Province of Ontario, Canada. Since ESO techniques can be adapted to a wide variety of problem types in which some or all of the system components are stochastic, the practicality of this approach can be adapted to many operational and strategic planning situations containing significant sources of uncertainty.

Keywords: Public sector decision making under uncertainty; Simulation-optimization; Waste management planning

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1. Introduction to solid waste planning

In public policy formulation, planners must balance and integrate many disparate factors prior to settling upon a final decision. To facilitate this process, various ancillary mechanisms for improving decision-making have assumed more prevalent roles, with the field of mathematical programming supplying several of these procedures. These planning models have been used in numerous applications to successfully facilitate the movement toward stated objectives in policy formulation [1,2]. It should be recognized, however, that any plan formulated by modelling methods would generally not be operationalized without supplementary decision-maker input [3], since supporting techniques applied without additional expert oversight are unlikely to produce policies that can simultaneously satisfy all conflicting dimensions [4,5].

The field of municipal solid waste (MSW) management affords a rich, illustrative environment of the disparate modelling techniques used to support policy formulation, since it possesses many of the conflicting characteristics generally encountered in public planning. Haynes [6] and Wenger and Cruz [7] reviewed several optimization techniques that have been applied to MSW planning problems and additional optimization examples have been considered in [8–12].

However, optimization techniques prove appropriate only for well-structured problems [13–15] and the numerous uncertain components prevalent within MSW systems render many optimization techniques unsuitable for practical implementation purposes [16–18]. Their major drawback is attributable to the fact that they have all been based upon deterministic methods and, therefore, provide no effective mechanism with which to incorporate system uncertainties directly into their solution construction.

1.1. Incorporating uncertainty into MSW planning

Precise analytical formulations of many complex systems do not often exist and, even when they do, frequently include highly non-linear, stochastic components. The complexity of planning in these situations can be significantly compounded by the fact that many system components cannot be known with certainty beforehand. Hence, in many "real-world" applications, the quality of information produced by deterministic optimization techniques can be rendered highly questionable when the input data cannot be expressed with precision. Data imprecision can be addressed through optimization approaches such as chance-constraint programming and fuzzy programming [4,19–21]. However, these types of methods cannot, in general, be effectively linked to the economic consequences of violating predefined system constraints, which is essential in policy-related analyses [20].

To counteract the many difficulties that discrete optimization experiences with data uncertainty, Huang et al. [22] applied grey programming (GP) techniques to MSW planning, using a case study from the Municipality of Hamilton–Wentworth in the Province of Ontario. Located at the western-most tip of Lake Ontario, this region encapsulates the industrial heartland of Canada. GP is a technique that readily processes interval data, thereby avoiding many of the problems encountered by other optimization methods when faced with parameter uncertainty. Since practitioners generally find it easier to specify estimates of fluctuation ranges than to determine appropriate distributional information, interval estimation proves especially meaningful in most practical settings [23,24].