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Modified differential evolution algorithm for the continuous network design problem

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Abstract

The Continuous Network Design Problem (CNDP) is recognized to be one of the most difficult problems in transportation field since the bilevel formulation of the CNDP is nonconvex. On the other hand, the computation time is crucial importance for solving the CNDP because the algorithms implemented on real sized networks require solving traffic assignment model many times, which is the most time consuming part of the solution process. Although the methods developed so far are capable of solving the CNDP, an efficient algorithm, which is able to solve the CNDP with less number of User Equilibrium (UE) assignments, is still needed. Therefore, this paper deals with solving the CNDP using MOdified Differential Evolution (MODE) algorithm with a new local search and mutation operators. For this purpose, a bilevel model is proposed, in which the upper level problem deals with minimizing the sum of total travel time and investment cost of link capacity expansions, while at the lower level problem, UE link flows are determined by Wardrop's first principle. A numerical example is presented to compare the proposed MODE algorithm with some existing methods. Results showed that the proposed algorithm may effectively be used in order to reduce the number of UE assignments in solving the CNDP.

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Keywords: Continuous network design problem; differential evolution; bilevel programming.

1. Introduction

A Continuous Network Design Problem (CNDP) is to determine the set of link capacity expansions and the corresponding equilibrium link flows for which the measure of performance index for the network is optimal (Chiou, 2005). The CNDP can be described as one of the most computationally intensive problem in transportation field. Since the multiple objectives exist in the CNDP, it can be formulated as bilevel programming model which is difficult to solve. The difficulty stems from solving the lower level problem for each feasible set

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of upper level decision variables. In the CNDP, upper level objective function can be defined as the sum of total travel time and investment cost of link capacity expansions whilst the lower level is formulated as traffic assignment model which can be static or dynamic.

The first formulation for solving the CNDP was proposed by Abdulaal and LeBlanc (1979) using Hooke-Jeeves (HJ) heuristic algorithm. Tan et al. (1979) attempted to solve the CNDP by expressing the traffic equilibrium problem by a set of nonlinear and nonconvex, but differentiable constraints in terms of path flow variables. Suwansirikul et al. (1987) developed Equilibrium Decomposition Optimization (EDO) algorithm for solving the CNDP. Marcotte and Marquis (1992) used an efficient heuristic procedure for solving the CNDP. In addition, sensitivity-based heuristic algorithms were developed for the CNDP in different studies (Cho, 1988; Friesz et al., 1990; Yang, 1995; 1997). Furthermore, Friesz et al. (1992) used Simulated Annealing (SA) approach to solve the CNDP. Their results showed that the proposed heuristic is more efficient than Iterative Optimization Assignment (IOA) algorithm, HJ algorithm and EDO approach. Davis (1994) used the generalized reduced gradient method and sequential quadratic programming to solve the CNDP. Meng et al. (2001) used single level model in solving the CNDP in order to avoid the disadvantages of the bilevel programming model. Chiou (2005) proposed gradient based methods to solve the CNDP and achieved good results especially when the congested road networks are considered. Similarly, Ban et al. (2006) presented a relaxation method to solve the CNDP when the lower level is a nonlinear complementary problem. Karoonsoontawong and Waller (2006) proposed SA, Genetic Algorithm (GA), and random search techniques to solve the mentioned problem. Their study showed that GA performed better than the others on the test networks. Xu et al. (2009) used SA and GA algorithms to find optimal solutions of the CNDP. They emphasized that quality of the results are dependent on the demand level. Wang and Lo (2010) proposed an approximation method for finding the globally optimal solution of the CNDP and Li et al. (2012) presented a viable global optimization method for the CNDP. Recently, Baskan and Dell'Orco (2012), Baskan (2013a) and Baskan (2013b) solved the CNDP using Artificial Bee Colony, Harmony Search and Cuckoo Search algorithms, respectively.

Up to date, studies have been focused on the CNDP are generally based on the heuristic approaches, and guarantee finding a solution which is at least locally optimal. Nevertheless, an efficient heuristic algorithm, which is capable of solving the CNDP with less number of User Equilibrium (UE) assignments, is still needed. Therefore, this paper deals with determining the optimal link capacity expansions for a given road network using Modified Differential Evolution (MODE) algorithm.

The rest of this paper is organized as follows. In Section 2, the problem formulation is summarized. In the next section, proposed solution method is presented. In Section 4, numerical applications are conducted on example test network. Conclusions are drawn in Section 5.

2. Problem formulation

The CNDP can be formulated as follows. The nomenclature used in the formulation is given in the table below.

$$\min_{\mathbf{x},\mathbf{y}} Z(\mathbf{x},\mathbf{y}) = \sum_{a\in A} (t_a(x_a, y_a)x_a + \rho g_a(y_a)) \tag{1}$$

$$\text{s.t.} \qquad 0 \le y_a \le u_a \,, \quad \forall a \in A \tag{2}$$

where $\mathbf{x}(\mathbf{y})$ is vector of the equilibrium link flows which is the solution of the following convex optimization problem:

$$\min_{\mathbf{x}} \; z = \sum_{a\in A} \int_0^{x_a} t_a(w, y_a)dw \tag{3}$$

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