Transportation Research Part C 25 (2012) 152–167

Contents lists available at SciVerse ScienceDirect

Transportation Research Part C

journal homepage: www.elsevier.com/locate/trc

A Hybrid Harmony Search and TRANSYT hill climbing algorithm for signalized stochastic equilibrium transportation networks

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ARTICLE INFO

Article history:
Received 13 July 2011
Received in revised form 18 May 2012
Accepted 21 May 2012

Keywords:
Equilibrium network design problem
Harmony Search
TRANSYT hill climbing
Stochastic user equilibrium
Traffic control

ABSTRACT

Determining the optimum signal settings in a road transportation network is an important issue for providing shorter travel time and lower fuel consumption. In the Stochastic EQuilibrium Network Design (SEQND) context, traffic signal setting problem has been widely formulated as an optimization problem which is addressed with both deterministic and heuristic approaches. While deterministic approaches such as gradient-based methods are preferred, they may not be effective since the problem contains several local optima and the decision space is highly convoluted. Recently, heuristic global search approaches such as Genetic Algorithms (GAs) are utilized to solve the SEQND problem which may be non-convex in nature. Although heuristic approaches are very effective at exploring the search space, they may require relatively long time to find the global optimum solution. Thus, a hybrid approach, which utilizes a local search method that fine-tunes the solution of the global search method, may provide more accurate results for SEQND problem. Thus, this study proposes "Hybrid Harmony Search and Hill Climbing with TRANSYT" (HSHCTRANS) model to solve the SEQND problem. In the HSHCTRANS model, meta-heuristic Harmony Search (HS) algorithm is employed as a global search method while the TRANSYT hill climbing routine is used for fine-tuning. It has been applied to an example signalized road network. The effectiveness of the hybrid HSHCTRANS over the HS and Genetic Algorithm (GA)-based models has been investigated in terms of network performance index (*PI*). Results showed that the hybrid HSHCTRANS model provided about 11% improvement when it is compared with GA-based model.

1. Introduction

The search for an optimal network performance of urban roads for given timing parameters and traffic volumes has attracted considerable attention during the last decades. The combination of traffic control and stochastic assignment problems, called Stochastic EQuilibrium Network Design (SEQND), has so far been formulated using two mathematical frameworks, which are mutually consistent (MC) and bi-level approaches, and procedures for determining optimum signal timings have been developed and continuously improved (Allsop, 1974; Gartner, 1974; Allsop and Charlesworth, 1977; Suh and Kim, 1992; Ceylan and Bell, 2004, 2005; Ceylan, 2006; Chiou, 2007, 2008). In order to provide significant improvement in network travel time and fuel consumption in the SEQND problem, traffic control parameters (cycle time, stage change times, the offsets, etc.) should properly be optimized.

Allsop and Charlesworth (1977) presented the MC approach, which is also known as the iterative optimization assignment (IOA) method, between traffic signal settings and link flows. In their study, the signal settings and link flows were

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http://dx.doi.org/10.1016/j.trc.2012.05.007

calculated sequentially by solving the signal setting problem for assumed link flows and carrying out the user equilibrium assignment for the resulting signal settings until convergence was achieved. The resulting mutually consistent signal settings and equilibrium link flows will, however, in general be a non-optimal solution as has been discussed by Gershwin and Tan (1979) and Dickson (1981). In addition, it is stated in the literature that the bi-level approach provides more stable and successful results than the MC approach (Suwansirikul et al., 1987; Wong et al., 1999; Ceylan, 2002; Ceylan and Bell, 2004).

In the bi-level formulation, the upper level deals with the system performance optimization with respect to the decision variables, while at the lower level a user equilibrium traffic assignment problem is solved. The dependence of equilibrium flows on the decision variables is treated as a constraint of the upper level and is solved by the lower level problem. Therefore, the SEQND problem can be regarded as a constrained optimization problem (Chiou, 2009). In the last decades, several solution methods have been developed to solve bi-level SEQND problem. These methods can be classified as deterministic and stochastic in nature. The deterministic methods can be classified as the linearization, sensitivity analysis and gradient-based local search approaches that require substantial gradient information to find a solution.

Heydecker and Khoo (1990) firstly proposed a linear constraint approximation to the equilibrium flows and solved the SEQND problem as a constrained optimization problem in a sequence of linear approximation. Application of sensitivity analysis for equilibrium network flows was introduced by Tobin and Friesz (1988). Extension of the application of sensitivity analysis of equilibrium network flows to a number of topics of interest within this aspect of transportation has been investigated in subsequent studies. As a practical way of solving this bi-level program, Friez et al. (1990) discussed a sensitivity analysis method, in which all the partial derivatives of the objective function and network flows, with respect to the decision variables, are taken into account. Furthermore, Yang and Yagar (1995) proposed a sensitivity analysis based (SAB) solution algorithm to solve the SEQND problem where a linearized sub-problem is formulated at current signal settings and solved by the simplex method. In fact that, due to the non-convex nature of the problem, the SEQND problem can locally be solved with those solution algorithms. Chiou (1999) used a mixed search with projected gradient method which was previously used by Sheffi and Powell (1983). Moreover, Chiou (2003, 2005) utilized some of those nonlinear methods for signal optimization problem joint with traffic assignment and presented some interesting methods and heuristics for finding their optimal solutions.

Even when both the upper level and the lower level consist of convex programming problems, the network design problem may be non-convex in the sense that there may be many local optima. This non-convexity implies a serious problem for deterministic algorithms (Bell and Iida, 1997). Stochastic based studies dealing with the solution of SEQND problem were performed by Friesz et al. (1992, 1993). In these studies, heuristic simulated annealing was employed to generate optimal solutions to the network design problem with variational inequality constraints. Yin (2000) has proposed a genetic algorithm based (GAB) approach for bi-level programming models in transportation research. It was stated that the GAB approach requires more computational efforts than the previous SAB algorithm but avoids the complex computation of the derivatives of link performance functions for equilibrium network flows. Teklu et al. (2007) presented a GAB method for optimizing traffic signals in a way that anticipates rerouting of traffic, and its application on the city of Chester was presented. The GAB method has given promising results on finding optimum signal timings with stable flows. Also, a simulation/optimization based traffic model, which utilizes GA for combining the assignment software Path Flow Estimator (PFE) and TRANSYT (Robertson, 1969; Vincent et al., 1980) traffic tool, is an important contribution to the area in recent works (Ceylan and Bell, 2004, 2005). The optimization procedure in TRANSYT is based on an iterative search technique, known as ''Hill-Climbing'' (HC), which basically searches for the best signal timings by a trial and error method. Ceylan (2006) has combined GA with TRANSYT HC optimization routine, referred to as GATHIC, and proposed a method for decreasing the search space to find optimal or near-optimal signal timings for area traffic control. The GATHIC was applied to a well-known road network in literature for fixed sets of traffic demand. It should be noted that the drivers' path choice behavior was not taken into account in the GATHIC model. Besides the traditional and heuristic methods, new researches are carried out on traffic signal optimization. Maher et al. (in press) has investigated the application of the cross-entropy method to two different types of signal optimization problems. In the first, there is no route choice and the traffic model used to evaluate any resulting signal timings is deterministic; whilst in the second, there is route choice and this is affected by the solution of signal times. However, the routing pattern is estimated by a Monte Carlo traffic assignment model, so that the returned value of the performance index is subject to random error. It is shown that both problems could be tackled by means of the cross entropy method.

One of the main purposes of this study is to investigate the applicability of the Harmony Search (HS) technique, which inspires from *musical improvisation process*, in the SEQND. This musical improvisation process can be adapted into engineering optimization processes in which the main objective is to find the global or near-global solution of a given objective function. In this adaptation, each musician is replaced with a decision variable. Therefore, the perfect harmony means the global or near-global solution. The reason for selecting HS for solving the SEQND problem depends on its simplicity in formulating, non-requirement for derivative information of the link performance functions and quite rapid convergence of the algorithm over the current heuristic methods such as GA with better values of objective function. The HS algorithm also considers several solution vectors simultaneously in a manner similar to GA. However, the major difference between the GA and the HS algorithm is that the HS generates a new solution using all the existing vectors, whereas the GA uses only two of the existing vectors. In addition, a very powerful subcomponent for HS diversification is the pitch adjustment operation. A small random amount is added to or subtracted from a decision variable stored in the memory. Pitch adjustment is carried out by tuning the pitch within a given bandwidth and it ensures that good solutions are retained while the randomization makes the