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# Development, application, and comparison of hybrid meta-heuristics for urban land-use allocation optimization: Tabu search, genetic, GRASP, and simulated annealing algorithms

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ABSTRACT

Land-use optimization problem (LUOP) that seeks to allocate different land types to land units involves various dimensions and deals with numerous conflicting objectives and a large set of data and variables. Single meta-heuristics are broadly developed and applied for solving LUOP. Despite the acceptable solutions derived from these algorithms, researchers in both academic and practical areas face the interesting question: can we develop an algorithm with better efficiency and solution quality? In the literature of operation research, hybridization, a combination of meta-heuristics, was introduced as a way of generating better algorithms. Therefore, this paper aims at developing novel algorithms through hybridizing Tabu search (TS), genetic algorithm (GA), GRASP, and simulated annealing (SA) and examining their quality and efficiency in practice. Accordingly, low-level teamwork GRASP–GA–TS (LLTGRGATS), high-level relay Greedy–GA–TS, and high-level teamwork SA were developed. Firstly, these algorithms were applied for solving small- and large-size single-row facility layout problem to evaluate their performance and functionality and to select the satisfactory algorithm in comparison with the other developed hybrids. Secondly, the selected algorithm, LLTGRGATS, and SVNS, a recent hybrid algorithm proposed for solving LUOP, were performed on a study area to solve a LUOP with two constraints and seven nonlinear objective functions. The outputs showed that the quality and efficiency of LLTGRGATS were slightly better than those of SVNS and it can be considered as a favorable tool for land-use planning process.


## 1. Introduction

As a variant of quadratic assignment problem, land-use allocation is a nondeterministic polynomial-time (NP)-hard problem that requires development and application of meta-heuristics for obtaining optimal solutions (Khalili-Damghani, Aminzadeh-Goharrizi, Rastegar, & Aminzadeh-Goharrizi, 2014). These algorithms can be classified into trajectory- and population-based categories. Trajectory algorithms are more efficient than population-based algorithms, but solution quality of population-based algorithms is better than that of trajectory algorithms (Talbi, 2002). Thus far, algorithms belonging to either trajectory- or population-based groups have been applied to solve land-use optimization problem (LUOP): (simulated annealing (SA): (J. C. Aerts & Heuvelink, 2002; Duh & Brown, 2007; Santé-Riveira, Boullón-Magán, Crecente-Maseda, & Miranda-Barrós, 2008; Sunil & Brian, 2004); Tabu search (TS): (Qi, Altinakar, Vieira, & Alidaee, 2008); genetic algorithm (GA): (Cao et al., 2011; Cao, Huang, Wang, & Lin, 2012; Holzkämper & Seppelt, 2007; Janssen, van Herwijnen, Stewart, & Aerts, 2008; Karakostas & Economou, 2014; Matthews, 2001; Stewart, Janssen, & van Herwijnen, 2004; Xiao, Bennett, & Armstrong, 2002; Zhang, Zeng, & Bian, 2010); Particle Swarm: (Liu, Lao, Li, Liu and Chen, 2012; Masoomi, Mesgari, & Hamrah, 2013); Ant Colony: (Liu, Li, Shi, Huang and Liu, 2012); and Bee Colony (Yang, Sun, Peng, Shao, & Chi, 2015)). Notwithstanding the good results reported by these studies, researchers in both academic and practical areas deal with the interesting question: can we develop a more efficient algorithm that generates solution(s) with better quality?

Hybridization of meta-heuristics that combines algorithms by relying on their strengths has been proposed as one of the methods for answering the above question. Recently, development and application of hybrid algorithms have attracted the attention of researchers in urban planning and its related fields. Liu, Ou, Li, and Ai (2013) hybridized particle swarm with GA through a combination of updating the process of particle locations with genetic operators to improve the quality of the land-use arrangements. Khalili-Damghani et al. (2014) hybridized TS, variable neighborhood search (VNS), and scatter search (SS) algorithms to address LUOP. Although these studies combined some algorithms for solving LUOP, the ability of low-level teamwork GRASP-GA-TS (LLTGRGATS), high-level teamwork SA (HLTSA), and high-level relay Greedy-GA-TS (HLRGGATS) has not yet been considered for solving

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LUOP. Thus, the objectives of this research were (1) to develop new hybrid algorithms and to evaluate them by solving small- and large-size benchmark problems and (2) to select an acceptable algorithm in comparison with the other hybrids developed in this paper and to compare the quality of the selected algorithm with SVNS by solving an allocation problem in a real study area.

In this paper, first, the objective functions and constraints are introduced. Second, the structure of the developed hybrid algorithms is described. Subsequently, these algorithms are evaluated by solving benchmark problems. Finally, the algorithm that generates more satisfactory outputs than the other hybrids is selected and applied to the study area along with SVNS, and conclusions are represented.

## 2. Literature review

Reviewing the literature of land-use optimization represents that several studies concentrated on land suitability and context-based objectives. These functions mainly include land suitability, compactness, and distance-related functions. Cao et al. (2011) applied maximization of GDP, geological and ecological suitability, compactness, compatibility and accessibility, and minimization of NIMBY influence and land-use conversion as the objectives of LUOP. Liu, Li, et al. (2012) considered maximizing suitability and compactness and minimizing conversion for allocating four land types in a study area. Liu et al. (2013) defined minimizing the distance of the allocated cell to its nearest developed area and maximizing the suitability, compatibility, and compactness for zoning the protected ecological area. Porta et al. (2013) focused on land suitability and the shape regularity derived from land-use patches to represent a high-performance GA for land-use planning. Karakostas and Economou (2014) considered suitability, potential factor, development resistance, and contiguity to find the optimal spatial distribution of wind farms. Alongside the aforementioned studies, some scholars attempted to engage the objectives pursued by stakeholders and mentioned in urban planning concepts. In line with the new urbanism, Haque and Asami (2014) tried to represent the government's planner and land owner/developer perspectives by defining land price maximization, incompatibility minimization, and price of a single plot maximization objectives. Following smart growth, Gabriel, Faria, and Moglen (2006) took four stakeholders into account: the government planner, land developer, conservationist, and environmentalist, by considering maximizing compactness and minimizing imperviousness measure and conversion of environmentally sensitive areas. In the present paper, a combination of objectives indicated in these studies is considered with respect to the potentially stakeholders that may engage in land-use planning process to represent LUOP more realistically and comprehensively because of taking into account the stakeholders' objectives and recent planning concepts simultaneously.

Different types of LUOPs usually have been solved by linear programming (LP) during the past decades. Chuvieco (1993) combined LP and GIS to find the optimal land-use distribution by considering rural unemployment minimization function subject to technical, financial, and ecological constraints. J. C. Aerts, Eisinger, Heuvelink, and Stewart (2003) used LP for implementing spatial allocation of different land types in a real study area. Because of the complexity and nonlinearity of LUOP objectives, two other methods were adopted for solving this type of problem in addition to LP: Pareto-based (Balling, Taber, Brown, & Day, 1999; Cao et al., 2011; Chandramouli, Huang, & Xue, 2009; Huang, Liu, Li, Liang, & He, 2013) and weighted-sum methods (Cao et al., 2012; Yang et al., 2015). Pareto-based methods work according to the Pareto set notion which assumes that the relative importance of objective functions is independent. Weighted-sum methods turn the multiobjective LUOP into a single-objective optimization problem by combining objective functions. The former one concentrates on exploiting the solutions, but often suffers from inadequate effectiveness, while the latter one is simple to implement with more effectiveness, but needs a priori knowledge and is unable to obtain nonconvex optimal solutions (Cao et al., 2012). However, this shortcoming can be eliminated by applying improved summation methods (e.g., goal programming). A variety of these approaches represent an urgent need for developing appropriate optimization algorithms to assist land-use planning process. Santé-Riveira et al. (2008) employed SA for land-use allocation by using the weighting method; Ligmann-Zielinska, Church, and Jankowski (2008) developed a density-based optimization technique to achieve optimum land-use arrangements by using the hop–skip–jump method; Zhang et al. (2010) developed a spatial optimization model for solving LUOP through integration of GA and multiagent system; Masoomi et al. (2013) adapted particle swarm optimization to find the optimum land-use layouts in a study area comprising several parcels.

Hybrid methods offer the possibility of generating algorithms with higher efficiency and/or solution quality than the solo ones, and as such, several scholars have represented hybrid algorithms' classification providing a great choice set to design hybrids and preparing opportunities for innovation in this research area (Drezner & Misevičius, 2013). El-Mihoub, Hopgood, Nolle, and Battersby (2006) focused on memetic algorithms and investigated improvising techniques including capability enhancement and setting control parameters. Raidl (2006) classified hybrid meta-heuristics on the basis of several criteria such as level of hybridization and order of execution. Talbi (2002) also grouped hybrid algorithms and introduced hybridization syntaxes in a multilevel hierarchical framework (low-level teamwork (LLT), high-level teamwork (HLT), and high-level relay (HLR)), which can be extended by flat categorization (e.g., homogenous vs. heterogeneous and partial vs. general). LLT hybrids work by replacing operators of a population-based algorithm with meta-heuristics to enhance the exploitation phase of the original algorithm. HLT algorithms divide the solution space into several parts that are searched by a number of meta-heuristics arranged in a predefined topology and designed solution-sharing strategies. HLR hybrids combine single algorithms in a pipeline structure where the output of each meta-heuristic is the input of another meta-heuristic. Considering these guidelines, Crainic, Gendreau, Hansen, and Mladenović (2004) proposed a cooperative VNS algorithm that can be regarded as a HLT meta-heuristic using a central-memory mechanism as the solution-sharing strategy to solve *p*-median problem; Moral and Dulikravich (2008) developed an evolutionary algorithm based on HLR notion; Xiao (2012) introduced five hybrid algorithms that can be classified in the category of high-level algorithms for solving *p*-median problem; Creaco and Pezzinga (2015) combined LP and GA by utilizing a low-level hybrid concept to minimize leakage in water distribution networks. Yet, few studies have been dedicated to develop new algorithms for solving LUOP using these hybridization concepts. In this paper, the three proposed algorithms are LLTGRGATS, HLTSA, and HLRGGATS. As GA, an algorithm compatible with the structure of LUOP, is powerful for exploring the solution space and is weak in exploiting the founded solutions, which often leads to immature convergence around the global optima (Jalali Naini, Jafari Eskandari, & Nozari, 2012), LLTGRGATS is developed according to LLT notion to enhance the exploitation phase of GA by combining it with two strong local search algorithms, GRASP and TS. Since SA, another algorithm widely applied for solving allocation problems, is appropriate for solution exploitation and is inappropriate for exploration of the solution space in comparison with population-based algorithms (Samadzadegan & Alizadeh Naeini, 2011), HLTSA is established to increase the exploration power of single SA. HLRGGATS is also developed to promote the quality of final solutions by generating a good population through Greedy for GA and exploiting the results through TS.

## 3. Objective functions and constraints formulation

The selected objectives, mathematically expressed in Table 1, are compactness, compatibility, suitability, mix use, green space area, commercial area, and FAR maximization.