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Time-dependent fuzzy random location-scheduling programming for hazardous materials transportation

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A R T I C L E I N F O

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A B S T R A C T

The tremendous use of hazardous materials has promoted the economic development, which also brings about a growing risk causing a widespread concern. In this work, we consider a location-scheduling problem on hazardous materials transportation under the assumption that transportation risks are time-dependent fuzzy random variables. First, we formulate a scheduling optimization model and design a fuzzy random simulation based genetic algorithm to optimize the departure time and dwell times for each depot–customer pair. Then we establish an expected value model and design a modified particle swarm optimization algorithm to minimize the en route risks and site risks. Finally, numerical examples are given to illustrate the effectiveness of the proposed models and algorithms.

1. Introduction

With the increasing demand on hazardous materials around the whole world, the transportation programming problems involving them that may lead to serious consequences have become a hot topic. However, though the depots location and the vehicles scheduling are closely related on hazardous materials transportation, the location-scheduling problem (LSP), optimizing the location of depots and simultaneous the scheduling of vehicles for ensuring the global optimality on risk management, receives minor attention. In this paper, we model to optimize location-scheduling programming for minimizing the total risk including en route risk and site risk.

Although the probability of hazardous materials accidents is very low, the consequences can be catastrophic. It implies that more realistic factors should be taken into account to reduce the loss. However, some realistic factors such as time-dependent risks and road conditions receive minor attention from both scientists and practitioners (Erkut et al., 2007). In this paper, we pay more attention on time-dependent risks and road conditions to optimize the location-scheduling strategy, which makes the hazardous materials transportation programming more practical.

The previous studies on hazardous materials transportation mainly focused on deterministic cases. However, uncertainty exists in hazardous materials transportation problems inherently. For example, travel time is generally random and surrounding populations are generally fuzzy influenced by weather conditions, traffic conditions, time intervals and others. This work takes fuzzy-randomness into account. To the best of our knowledge, there is no such study in location-scheduling programming for hazardous materials transportation.

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The rest of this paper is organized as follows. Section 2 reviews literature on the location problem (LP), vehicle scheduling problem (VSP) and LSP related to hazardous materials transportation. In Section 3, a scheduling optimization model and an expected risk minimization model are given. In Section 4, a fuzzy random simulation based genetic algorithm (FRS-GA) and a greedy method based adaptive hybrid particle swarm optimization (GM-AHPSO) algorithm are designed. In Section 5, we provides numerical cases to show the feasibility and the optimality of the proposed algorithms, and summarize the findings from the computation results compared with other algorithms.

2. Literature review

LSP is a coordinated combination of LP that determines the location of depots and VSP that determines the scheduling of vehicles. In the field of hazardous materials transportation, the characteristic of low-probability high-consequence makes it necessary to consider the LP and VSP simultaneously, which would be useful to reduce the total risk. This section reviews literature on LP, VSP and LSP, related to hazardous materials transportation.

2.1. LP, VSP and LSP

The LP was initially studied by Cooper (1963) and VSP was arised in the operational planning process of public transportation such as Saha (1972), Gillett and Miller (1974) and Gavish and Shlifer (1978). Their works were extended to many other cases. For example, Murtagh and Niwattisyawong (1982) proposed the capacitated LP, Leurent and Boujnah (2014) provided a novel network model for parking lot choice, Cook and Russell (1978) studied the stochastic routing and scheduling problem with time windows, Powell (1986) studied the dynamic VSP, Karuno and Nagamochi (2003) studied the multi-vehicle scheduling problem, and Sun et al. (2014) put forward a multi-objective model for train routing problem combined with scheduling on high-speed railway network.

As the combination of LP and VSP, the LSP received little attention and developed relatively late. In the field of supply chain, Mousavi and Tavakkoli-Moghaddam (2013) built a two-stage mixed-integer programming model for solving the location of cross-docking centers and the scheduling of vehicles, aiming at efficiently servicing customers with minimal cost. Rita et al. (2015) solved the LSP by a skewed general variable neighborhood search based heuristic.

2.2. Particle Swarm Optimization (PSO) in LP, VSP and LSP

PSO is a swarm intelligence based heuristic optimization algorithm initialed by Kennedy and Eberhart (1995) which took its inspiration from the cooperation and communication exchange of a flock of birds. In the field of transportation, as an efficient optimization method, PSO is very popular especially during the last few years. Sevkli and Guner (2006) embedded a local search to the PSO algorithm for the uncapacitated LP, and proved that it could generate more robust results than the compared methods. In Wang and Watada (2012), a value-at-risk based facility location model was built. The authors designed a hybrid PSO algorithm, in which a continuous Nbest–Gbest-based PSO was used to deal with the continuous capacity decisions, and a genotype-phenotype-based binary PSO was used to deal with the binary location decisions. Gong et al. (2012) proposed a set-based PSO to solve the discrete vehicle routing problem with time windows. Wang et al. (2009) established a multi-depots VSP model and designed a two-phase PSO to solve it. The work by Peng and Chen (2009) was the first attempt to propose a PSO algorithm for the location-routing problem. The authors divided the original problem into a location-allocation subproblem and a general vehicle routing subproblem, and then solved each subproblem by using the PSO method embedded in the general framework for the problem-solving procedure.

Due to the simplicity in coding and great ability of global exploration, PSO usually outperforms other algorithms in optimization problems. Through studying on literatures above, we can find that PSO algorithm has been successfully utilized in various transportation problems. In this work, we will propose a modified PSO algorithm for solving the LSP on hazardous materials transportation.

2.3. Hazardous materials transportation

Risk is the most commonly used optimization objective in hazardous materials transportation problems in view of the characteristic of high consequence. The most popular risk measure is defined as the product of accident probability and consequence. Laarabi et al. (2014) pointed out that it is important to mitigate either the probability of occurrence or magnitude of the consequences. Other measures include the incident probability (Saccomanno and Chan, 1985), the population exposure (ReVelle et al., 1991) and others. Xie et al. (2012) considered multi-modal transportation problem that simultaneously optimized the locations of transfer yards and transportation routes including highway and railway modes, in order to minimize link risk and the risk during the transfer process. Chakrabarti and Parikh (2013) estimated consequence of an incident by the amount of hazardous materials released, toxicity of the chemical, population, environmental characteristics and some other factors. Raemdonck et al. (2013) divided the transport route into different segments with a fixed length. In this methodology, a global risk map was drawn based on an average probability of occurrence of a catastrophic accident. Ahmed and Abdel-Aty (2013) presented a framework for real time risk measure by fusing data from two different detection