

Current Trends in Simheuristics: from smart transportation to agent-based simheuristics

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Abstract—Simheuristics extend metaheuristics by adding a simulation layer that allows the optimization component to deal efficiently with scenarios under uncertainty. This presentation reviews both initial as well as recent applications of simheuristics, mainly in the area of logistics and transportation. We also discuss a novel agent-based simheuristic (ABSH) approach that combines simheuristic and multi-agent systems to efficiently solve stochastic combinatorial optimization problems. The presentation is based on papers [1], [2], and [3], which have been already accepted in the prestigious Winter Simulation Conference.

Index Terms—simheuristics, stochastic optimization, logistics & transportation, agent-based simheuristics.

I. INTRODUCTION

Real-life optimization problems are often *NP-hard* and large-scale in nature, which makes traditional exact methods inefficient to solve them. Thus, the use of heuristic and metaheuristic algorithms to obtain high-quality solutions in low computing times is required. With the increasing advances in computing hardware and software, simulation has become a ‘first-resource’ method for analyzing complex systems under uncertainty [4]. Thus, simulation is frequently employed in areas such as logistics and transportation, manufacturing, supply chain management, or smart cities. These systems are modeled and then simulated to get insights on their performance under different base scenarios. Simulation, however, is not an optimization tool. Thus, whenever a decision maker aims to find an optimal configuration for a system, she requires the use of optimization methods. Often, the associated optimization problems are addressed by assuming deterministic inputs and constraints, which allows us to simplify them but at the cost of not considering the real-life uncertainty that characterizes these systems.

Simheuristic algorithms integrate simulation methods inside a metaheuristic optimization framework to deal with large-scale and *NP-hard* stochastic optimization problems. Hybridization of simulation techniques with metaheuristics allows us to consider stochastic variables in the objective function of the optimization problem, as well as probabilistic constraints in its mathematical formulation. As discussed in [5], the simulation component deals with the uncertainty in the model and provides feedback to the metaheuristic component in order to guide the search in a more efficient way. Notice also that, when dealing with stochastic optimization problems, performance statistics other than expected values must be taken into account: while in deterministic optimization one can focus on finding a solution that minimizes cost or maximizes profits, a stochastic version of the problem might require

that we analyze other statistics such as its variance, different percentile values, or its reliability level.

The main goals of this presentation are: (i) to provide a commented review of recent applications of simheuristics in the area of transportation; and (ii) to analyze trends as well as open research lines.

II. RECENT APPLICATIONS IN TRANSPORTATION

[6] discuss the need for optimizing urban waste collection in modern smart cities and formulate the problem as an extension of the vehicle-routing problem. The authors first develop a competitive metaheuristic, based on a variable neighborhood-search framework, to solve the deterministic variant. Then, they extend their approach into a simheuristic to cope with unexpected waste levels inside the containers. Their algorithm is tested using a large-scaled benchmark set for the waste-collection problem with several realistic constraints. Their results include a risk analysis considering the variance of the waste level and vehicle safety capacities.

The uncapacitated facility-location problem with stochastic service costs is analyzed in [7]. First, the authors propose an extremely fast savings-based heuristic, which generates real-time solutions for the deterministic version of the problem. This can be extremely useful in telecommunication applications, where ‘good’ solutions are needed in just a few milliseconds for large-scale networks.

[8] propose a simheuristic algorithm for solving the arc-routing problem with stochastic demands. Here, the authors use Monte Carlo simulation to extend the RandSHARP heuristic, which was originally designed to solve the deterministic version of the problem. During the design of the routing plan, they make use of safety stocks, which allow vehicles to deal with unexpectedly high demands during the actual distribution process.

[9] consider a stochastic version of the capacitated facility-location problem, proposing two facility-location models representing alternative distribution policies in e-commerce (outsourcing vs. in-house distribution). The multi-period inventory-routing problem with stochastic customer demands is analyzed in [10]. A variable neighborhood search is extended into a simheuristic algorithm to consider variations in the forecasted demands. With the aim of finding optimal refill policies for each customerperiod combination, the authors take into account that the quantity serviced at the beginning of one period will affect the inventory levels at the end of that period.



III. CURRENT TRENDS

Some of the following trends in the use of simheuristics can be identified and are expected to play a relevant role in future publications on this topic, therefore constituting open research lines to be yet fully explored:

- *A higher level of simulation-optimization integration*: a deeper integration between the metaheuristic component and the simulation component, including increasing use of the feedback provided by the simulation better to guide the search for better solutions.
- *Additional objectives*: a rising interest in considering optimization goals different from the expected value of a solution for the stochastic optimization problem; this includes measuring other statistics reliability/robustness levels, and even considering multi-objective optimization problems.
- *Systems of increasing complexity*: moving from isolated logistics or transportation problems to integrated problems that reflect the complexity of supply networks, where interactions between different echelon stages also need to be considered in order to increase global efficiency.
- *Use of more sophisticated simulation approaches*: as the complexity of the systems increases, more advanced simulation approaches are required to take into account the dynamic and possibly nonstationary time-evolution of the system and the interactions among its many components.
- *Enhanced identification of promising solutions*: to speed up the computations, during a typical simheuristic process only a reduced set of solutions are classified as ‘promising’ and sent to the simulation component; enhanced strategies to classify a new solution as a promising one can be employed.
- *Statistically significant number of runs*: in some of the examples reviewed in this paper, a 2-stage approach is used; in the first stage the promising solutions are simulated using a reduced number of runs, while in the second stage longer simulations are executed on the ‘elite’ solutions provided in the first stage to increase the statistics’ accuracy and precision. However, statistical concepts could be employed to set the precise number of runs required in each stage in order to obtain estimates with a given level of precision.
- *Extending the application fields*: so far, most simheuristics have been applied in the area of transportation, logistics, and production. However, similar stochastic optimization problems can be found in other application fields such as telecommunications, finance, health-care systems, and smart cities.
- *Heuristic-supported simulation*: while the examples reviewed here refer to optimization problems in which simulation is used to support the search carried out by the metaheuristic, it is also possible to use heuristics or metaheuristics to optimize certain system parameters during a large simulation experiment.
- *Integration with machine learning*: being a flexible and relatively simple approach, simheuristics can be integrated with machine-learning approaches and, in particular, with learnheuristics in order to consider optimization problems with dynamic inputs.
- *Multi-population simheuristics*: all the examples reviewed here are based on single-population metaheuristics; however, integration of simulation within multi-population metaheuristics (e.g., genetic algorithms, etc.) might be worth exploring too since different individuals in a population might be based on different statistics obtained from the simulation component.
- *Agent-based simheuristics*: similar to the way agent-based modeling and simulation extends the more traditional concept of discrete-event simulation and benefits from distributed and parallel computing systems, one could consider agent-based simheuristics as a multi-agent extension of the simheuristic concept, where each agent is an autonomous and differentiated simheuristic algorithm that interacts with the rest of the agents while searching for a near-optimal solution to a complex and stochastic combinatorial optimization problem.

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