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Assigning Metaheuristics to a Logistics Problem: a Novel Classification System for Algorithms and Problems

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Metaheuristic algorithms applied to NP-hard problems are proven effective techniques in the field of optimization to ensure a good result within an acceptable calculation time. However, finding a suitable technique for optimizing a complex problem is not an easy task since there are hundreds of methods. The majority of metaheuristic research is characterized by developing a new algorithm for a task or modifying or improving an existing technique. The reuse of metaheuristics is small compared to the fact that up to 30+ new procedures can be presented in the scientific community every year. Metaheuristic algorithms have already been grouped in countless ways, but not based on their components and structural elements, which are responsible for the basic optimization performance of the given method. The grouping of the problems to be solved is also not typical in terms of which method can be used to solve them effectively. This paper contributes to filling this gap by introducing a novel classification system for algorithms and problems in terms of variables or based on the type of task. Two main categories were distinguished for both logistic tasks and metaheuristic algorithms: discrete and continuous. Linking the nature of the variables between the task and the algorithm is a significant step forward in choosing an efficient metaheuristic with a high probability for a logistics problem. This can increase the efficiency of solving logistics problems and expand the use of the latest optimization techniques.

1. Introduction

Due to their complexity, many logistics tasks and problems belong to NP-hard problems. For this reason, the literature considers metaheuristics to be the most suitable for solving these tasks (Sörensen and Glover, 2010), considering the priority of time and solution quality. There are hundreds of metaheuristic algorithms (Ma et al., 2023) and thousands of articles dealing with their efficient problem-solving. However, the question arises. If there is a problem, how can the appropriate optimization technique and algorithm be selected for it? If there is such a large set containing hundreds of different algorithms, why is there little reuse of metaheuristics (Swan et al., 2022)? What can help professionals and industry workers to choose the right algorithm? These questions are the focus of this paper.

Until now, metaheuristics and problems have not been grouped based on their components and structural elements, which are responsible for the basic optimization performance of the given method. Based on these, the problem can be formulated as follows: No framework or selection structure can assign metaheuristics to a problem that is most likely to solve the given problem correctly. All this is based on general information and schemes, not in the case of specific, special tasks.

To make it easier to associate a metaheuristic with a specific logistics problem, the authors introduced a new kind of classification of logistics tasks according to characteristics important for optimization. Based on the variables and the nature of the problem, 2 main categories were distinguished: discrete and continuous. The authors also examined what kind of problems can be efficiently solved with the given algorithm based on the literature, and based on this, the procedures were classified into 2 main categories: metaheuristics suitable for solving discrete and continuous tasks were distinguished. Based on the similar classification principle of logistic tasks and metaheuristic algorithms, the authors believe that a metaheuristic procedure suitable for solving a given problem can be defined. All of this contributes to increasing practical applications and efficiency in the field of logistics as well.

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The paper presents a framework based on which the most likely suitable optimization procedure can be selected for given variable tasks. A kind of reverse optimization is presented: a technique is not modified and adapted to a task, but the techniques providing a possible good solution for a task type are given, promoting the reuse and industrial applicability of existing metaheuristic procedures.
The paper is structured as follows: in section 2, the literature related to the topic is reviewed. Section 3 presents the selection framework. In section 4, an efficiency study is described, and finally, in section 5, the paper's conclusions and further research directions are presented.

2. Literature review

Due to their NP-hard complexity, metaheuristics are often applied to logistics problems. These algorithms have already been used for shop scheduling tasks (Coelho and Silva, 2021) and Resource-Constrained Project Scheduling Problems (Pellerin et al., 2020), but they have also proposed an algorithm that can be used in any intelligent decision-making system as an optimization module to increase accuracy and efficiency (Keivanian and Chiong, 2022). According to Ezugwu et al. (2021), it is possible to identify metaheuristics that have already been successfully applied to several problems (for example, the Vehicle Routing Problem). It is also useful to define the parameter settings of the algorithm for specific tasks (Chirwa et al., 2024). There are many research studies to solve logistics and supply chain problems, and it is difficult to summarize the results already achieved in each small area and to determine the best solution technique for the given problem, the reason, and details of the usefulness of the procedure.
Real optimization problems (e.g., logistics, transportation, engineering design) contain both continuous and discrete variables. This is also why it is difficult to assign a suitable metaheuristic to a problem since a metaheuristic algorithm cannot efficiently handle tasks containing mixed variables. One reason for this is that standard metaheuristics are designed to solve either continuous or discrete optimization problems (Talbi, 2024). Designing an algorithm is time-consuming and expensive, and the process itself is rarely documented (because of this, the process of thought is often untraceable, and it is not clear what motivated certain design decisions) (Swan et al., 2022).
Finding the right metaheuristic for a specific problem is very difficult. This hinders the re-implementation of algorithms, although the primary goal of research is to optimize practical tasks. The work is further complicated by the exponential growth of papers: new research materials appear every day.
The more frequent reuse of algorithms is further hampered by the lack of systematics for practical problems. It would be important to organize and classify practical problems according to aspects that can be connected to the operating mechanisms of algorithms. With the help of this, potentially suitable metaheuristics for a given problem can be selected more likely.
The aim of this paper is to find the components between logistic problems and metaheuristics, which can be used to determine the algorithm that provides a possible good solution for a given task. The general goals of the papers are to create, improve, or compare a metaheuristic with other metaheuristics to find out which algorithm performs best. But it is almost impossible to tell based on the results of thousands of papers. The primary aim of this paper is to promote more frequent reuse of metaheuristics by applying a general scheme. This is necessary because the thousands of scientific works and the hundreds of metaheuristics are less valid in practice. Efficiency, transparency, and sustainability can also be improved by using existing techniques instead of creating new ones.

3. A novel classification of logistic problems and metaheuristics

Most logistical problems are extremely complex and complicated tasks. Optimization is crucial in countless areas: the proper allocation of resources, minimizing the time or distance traveled, choosing the right warehouse structure, and the proper placement of depots are just a few examples of the countless tasks to be solved. In many cases, these tasks can only be performed properly if the processes are coordinated and properly optimized. Figure 1 shows the structure of the framework, which helps to assign a metaheuristic with a possible good solution to a task.
The steps of the modeling procedure are as follows: 1. Definition of the problem; 2. Brief description of the problem (goals, constraints, etc.); 3. Defining the nature of the problem (discrete or continuous); 4. Literature review of algorithms; 5. Identifying metaheuristics that can provide a possible good solution; 6. Selection of a specific algorithm; 7. Application of metaheuristics to the specific task.

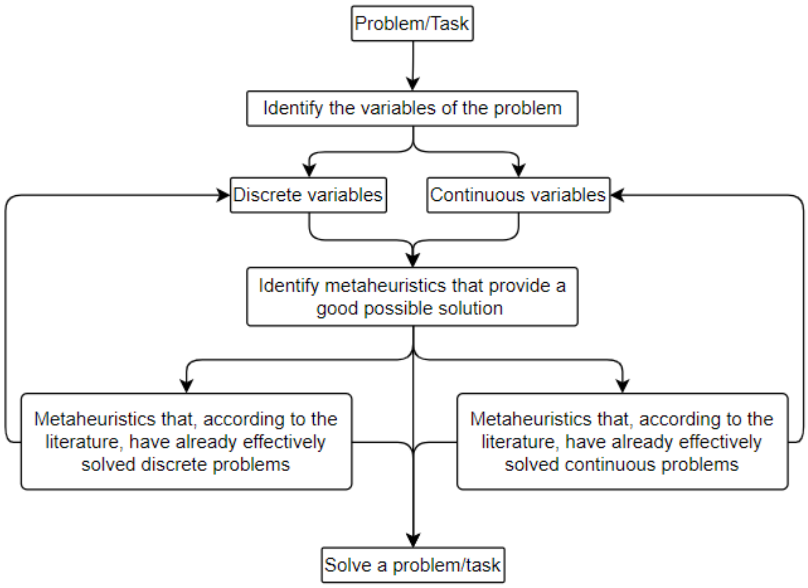

Figure 1: Framework for choosing an optimization technique

This is a new type of selection method, where the main hypothesis is that a logistics problem consisting of discrete or continuous variables can most likely be efficiently solved with metaheuristics that, based on the literature, have already been successfully applied to solving discrete or continuous tasks. Therefore, it is necessary to determine whether the nature of the problem is discrete or continuous. It is advisable to identify the goal and the most important constraints. Examples of this can be seen in Table 1.

Table 1: Classification of logistics problems (The nature of the tasks and their most important goals and constraints)

Logistical problem	Description/Purpose	Nature of the problem
Determining the location of warehouses	Optimizing network design by evaluating up to thousands of configurations and selecting the best one. Goal: minimizing total costs. Constraints: cost, distance, certain service level limits.	Discrete
Inventory management	Determination of order quantities, safety stock levels, determination of optimal order points. Goal: balance between storage costs and shipping costs. Constraint: cost.	Continuous
Vehicle Routing Problem (VRP)	Determination of optimal route and means of transport. Goal: minimize travel distance, time, or cost. Constraints: number and size of resources.	Discrete

There are hundreds of different metaheuristic algorithms, which have been classified in many different ways. One of the latest classification techniques was presented by Darvishpoor et al. (2023). Based on these groups, the authors selected a metaheuristic from each group, which was examined in terms of whether the given algorithm had already been successfully applied to solve discrete or continuous problems (Table 2).
Further literature research was carried out according to the scheme below: The selected algorithms were examined according to how many papers deal with the given metaheuristics at some level (Database: ScienceDirect). Figure 2 shows the results of searching for the name of the algorithm. According to the authors' assumption, the more articles deal with a metaheuristic, the more data and information can be obtained from the papers. Therefore, the given algorithm received a + sign above 10,000 hits and a ++ sign above 100,000. The authors also examined whether the title of a publication included the name of the metaheuristic and the nature of the problem (discrete or continuous). It was considered important to see how easy or difficult it is to search for problems and algorithms. If a publication containing this information was found in the first-page listing

(metaheuristics marked with an asterisk in Figure 2), the metaheuristic was given an extra + sign. The results obtained in this way are included in Table 2.

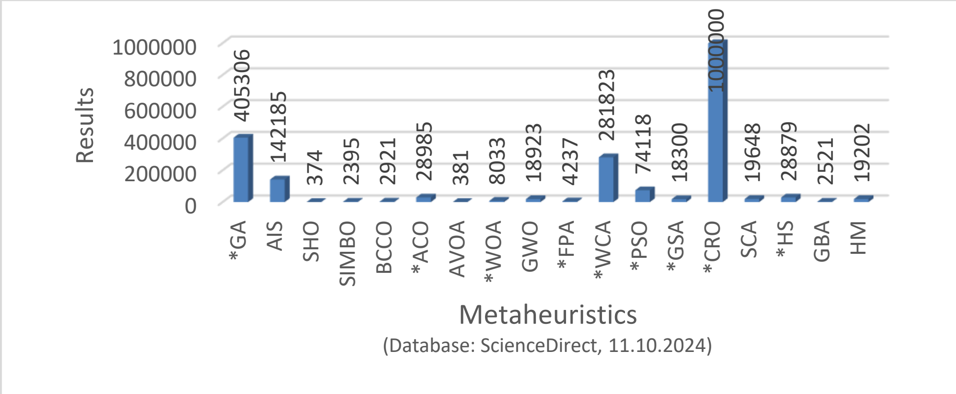

Figure 2: Literature statistics

Table 2: Metaheuristics for discrete or continuous variable problems

Metaheuristic	Variable's type (Problem)	Literature results
Genetic Algorithm (GA)	discrete-continuous	+++/+++
Artificial Immune System (AIS)	discrete	++
Selfish Herd Optimizer (SHO)	continuous	
Swine Influenza Models-Based Optimization (SIMBO)	continuous	
Bacterial Colony Chemotaxis Optimization (BCCO)	continuous	
Ant Colony Optimization (ACO)	discrete	++
African Vultures Optimization Algorithm (AVOA)	continuous	
Whale Optimization Algorithm (WOA)	continuous	+
Grey Wolf Optimizer (GWO)	continuous	+
Flower Pollination Algorithm (FPA)	continuous	+
Water Cycle Algorithm (WCA)	discrete	+++
Particle Swarm Optimization (PSO)	discrete	++
Gravitational Search Algorithm (GSA)	continuous	++
Chemical Reaction Optimization (CRO)	discrete	+++
Sine Cosine Algorithm (SCA)	discrete	+
Harmony Search (HS)	discrete	++
Golden Ball Algorithm (GBA)	discrete	
Hybrid Metaheuristic (HM)	discrete	+

With the help of these data, metaheuristics that provide a possible good solution for a given task were determined. The list below contains one example, highlighting which algorithms are primarily recommended for use based on the above (**+++**,++):
Problem1 - Determining the location of warehouses (nature of the problem: discrete): **GA**, AIS, ACO, **WCA**, PSO, **CRO**, SCA, HS, GBA, HM.
Problem2 - Inventory management (nature of the problem: continuous): **GA**, SHO, SIMBO, BCCO, AVOA, WOA, GWO, FPA, GSA.

4. Efficiency test of the selection method: Algorithm for Traveling Salesman Problem

The Traveling Salesman Problem (TSP) is the most well-known combinatorial NP-hard optimization problem. Many logistics problems, such as vehicle routing, distribution and network optimization, etc., can be transformed into TSP (Wang and Han, 2021). TSP poses the following question: „Given a list of cities and the distances between each pair of cities, what is the shortest route that visits each city precisely once and returns to the initial city?" (Rajwar et al., 2023). The TSP is a widely researched and popular area with a wide range of practical applications, such as production scheduling, material flow planning problems, waste collection management (Pop et al., 2024), order picking problems, frequency assignment problems in communication networks, etc. (Jati et al., 2023).

Using the framework, based on the steps below, the authors chose an algorithm providing a possible good solution (Which does not guarantee the best possible solution for the task, but that is not the goal here. The goal is to have a potential solution technique for a problem, even if there is not much time to choose and there is less loss with a medium-quality solution than the absence of a complete solution.):
1. The problem: Travelling Salesman Problem (TSP)
2. A brief description of the problem: Given a list of cities and the distances between each pair of cities. The aim is to find the shortest route that visits each city precisely once and returns to the initial city.
3. The nature of the problem: TSP is a combinatorial problem with discrete variables.
4.Identifying metaheuristics that can provide a possible good solution: It was necessary to identify metaheuristics that, based on the literature, have already effectively solved tasks of a discrete nature. (Examples in Table 2.)
5. Selecting a specific algorithm: Ant Colony Optimization was chosen.
6. Application of metaheuristics to a specific task.
The TSP contains discrete variables, so based on the above, the Ant Colony Optimization algorithm can provide a possible good solution. We tested the algorithm (ACOn, programming language: Python) created on the basis of expert knowledge gathered from the research materials belonging to this metaheuristic for tasks with n=50 cities (symmetric matrix). The goal was to find the shortest path based on Eq(1).

$$\sum_{i=1}^{50}\sum_{j=1}^{50} d_{ij}x_{ij} \;\rightarrow min \tag{1}$$

Solution with ACOn:
Best Tour: [40, 41, 18, 38, 49, 46, 19, 37, 44, 17, 4, 36, 7, 43, 6, 28, 1, 26, 33, 29, 32, 0, 31, 21, 20, 2, 45, 5, 34, 27, 15, 48, 25, 35, 3, 13, 24, 22, 10, 9, 8, 14, 16, 42, 30, 12, 23, 47, 39, 11]
Best Distance: 3315
Fine-tuning the parameters can further improve the efficiency of the procedure. Table 4 shows the parameter data for the best result.

Table 4: Parameter settings (ACOn)

Parameter	Value
num_ants	100
num_iterations	200
alpha	1.0
beta	2.0
decay_factor	0.5

The results of the 20 runs are shown in Figure 3, highlighting the best result (run 11).

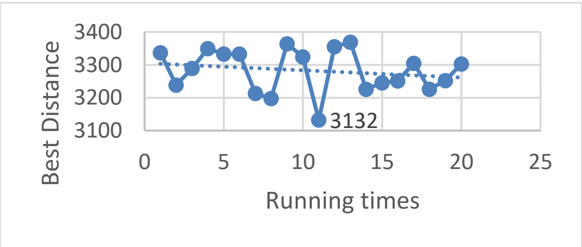

Figure 3: Running results ACOn-TSP

The metaheuristics selected using the framework effectively solved the simple TSP, a problem consisting of discrete variables.

5. Conclusions

The practical application of metaheuristics and the reuse of existing algorithms is not an easy task. In addition, the authors found that in countless cases in industry, events do not take place according to the predetermined scenario. The uncertain environment, the complex problems, and, in many cases, the conflicting tension of the results expected within a short period of time led to the search for a possible solution that would facilitate and speed up the time devoted to optimization while ensuring an acceptable result.

The classification of algorithms and tasks to be solved according to a similar principle was identified as a shortcoming. To solve these problems and shortcomings, the authors introduced a new classification principle: they classified both logistic problems and metaheuristics into discrete and continuous groups. They have developed a method that can be used to assign a metaheuristic to a logistics problem with high probability and be able to handle it efficiently. As a first step, the nature and variables of the problem to be solved were examined (discrete or continuous). After that, metaheuristics were examined based on the fact that, according to the literature, mostly discrete or continuous problems have already been solved effectively. Finally, metaheuristics were associated with the problem to be solved based on common characteristics. The classification of logistic problems and metaheuristics along a similar, novel principle is useful and can facilitate the choice of the appropriate optimization method. The authors demonstrated the suitability of the framework through a specific example. With the help of this, the authors supported their proposition that it has the right to categorize logistics tasks and algorithms according to a novel principle. A possible good framework for facilitating the decision process has been implemented, which can contribute to more frequent reuse of metaheuristics and their real industrial application, increasing efficiency and sustainability. The current research provides countless additional research directions and goals: assigning specific parameters to both logistics tasks and metaheuristics, identifying common points based on the parameters and narrowing down the possible methods that provide a good solution, extending the study to even more metaheuristics, solving specific logistics tasks is the framework with metaheuristics chosen based on.

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