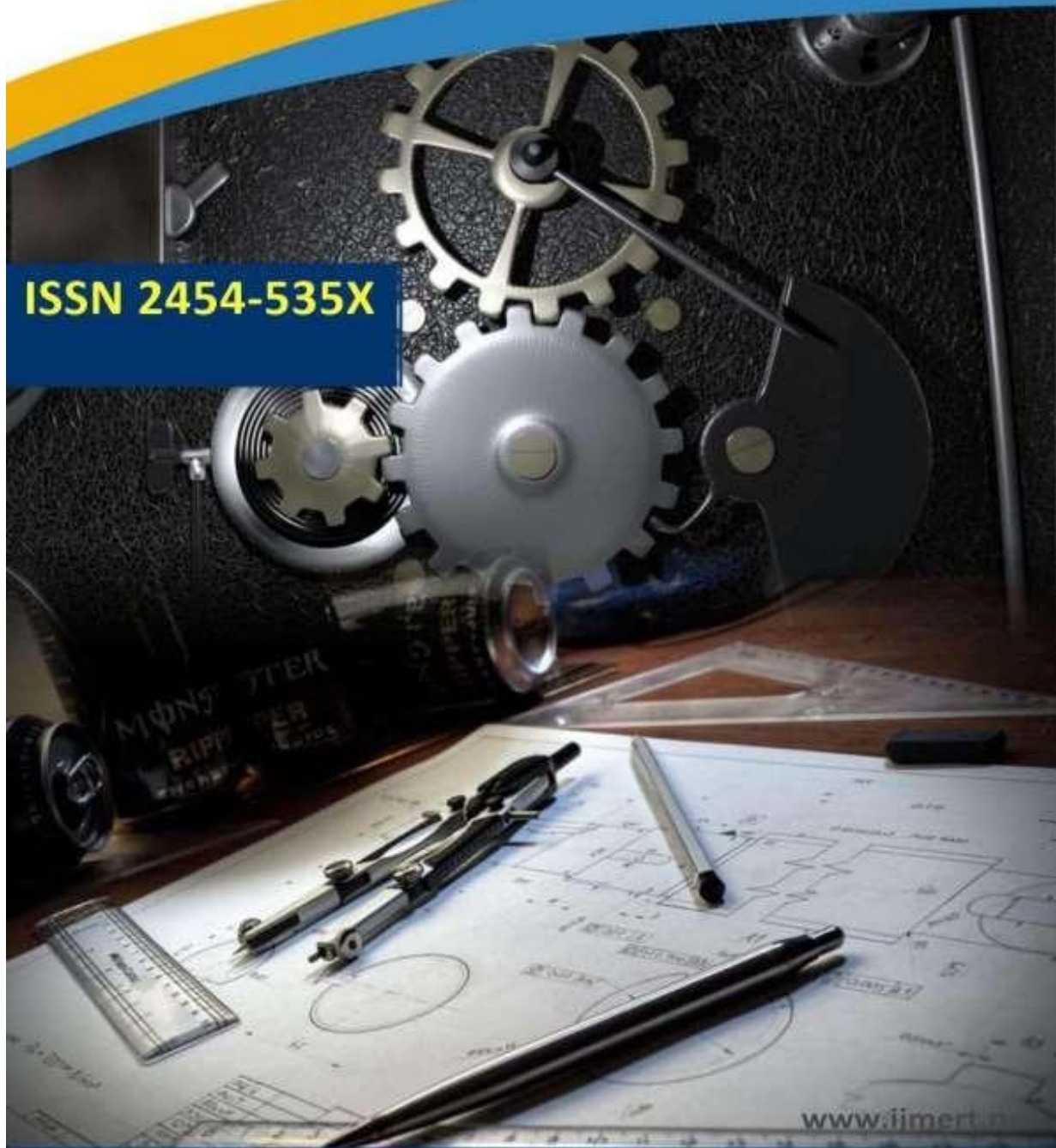




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Industrial Picking and Packing Problem: Logistic Management for Products Expedition

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ABSTRACT: The picking and packing problem is one of the considerable importance problems in logistics and widely arises in many industrial engineering applications. This paper investigates a single container picking and pack problem, which aims to pick a set of equal-dimensions boxes and pack them into a single container such that the utility of the boxes is maximized while the weight constraint of the container is satisfied. The problem considered in this study is formulated as a zero-one Knapsack Problem (0/1 KP). Due to the NP-hardness of the 0/1 KP problem, an Ant Colony Optimization (ACO) algorithm is proposed. Then to improve approximate solution quality, a new heuristic information is proposed based on problem-specific knowledge. The experimental outcomes show that the developed ACO algorithm is capable of solving the problem even with two hundred boxes efficiently, whilst requiring the same amount of computational effort.

KEYWORDS: *Picking and Packing Problem; Logistic; Knapsack Problem; Industrial Engineering; Ant Colony Optimization*

INTRODUCTION

Global industry refers to the world in which items are manufactured in one location and purchased by customers in another. Making the most use of the area allotted for product exploration is crucial from an economic standpoint. The selecting and packing optimization problem is to assign a collection of varied items to bigger standardized stock units with the goal of minimizing waste and maximizing utility in various real-world manufacturing (i.e., fabric, wood, glass, electronic, steel,...) [1]. In the context of industrial engineering, logistic refers to the process of organizing and managing the movement and storage of commodities from the point of manufacture to the point of consumption in order to fulfill the

a. Container



b. Pallet



Figure 1. Types of containers⁷⁴

In this paper, the considered problem is to deal with n boxes that are required to be loaded into a container. Each box has the same width, height and depth. On other hands, the weights and utilities (i.e. profit) of the boxes are different. Also, the container has a weight restriction. The problem is to pick a subset of boxes and packing them into the container so that the maximum profit is loaded while the weight constraint of the container is satisfied. Some authors may be imposed other constraints such as the distribution of the weight in the container need to be balanced or

restrictions on how many boxes may be put on top of each other, or the need to place boxes from one lot next to each other [4]. However, the problem considered in this paper is limited to only weight constraint of the container. This problem is often referred to knapsack problem. The general name of the problem if it includes additional constraints is a d-dimensional knapsack problem [2]. Some authors also include the term zero-one in name of the problem (i.e. 0/1 knapsack problem) which means that each box has two options: selected or not [5]. In operation research, this problem was proved to

be NP-hard problems with enormous search spaces [6].

Like for many NP-hard combinatorial optimization problems, exact and meta-heuristic algorithms have been developed for solving 0/1 knapsack problem. Exact methods often fail in solving the problem with large number of variables [7]. A new class of algorithms called meta-heuristic have yielded very good results so far including simulated annealing, tabu search, genetic algorithm and ant colony optimization. Ant Colony Optimization (ACO) is population-based approach which has been successfully applied to several NP-hard combinatorial optimization problems [8]. The behaviour of this algorithm is inspired by that of real ants. An important behaviour of ants is how they can find the shortest paths between food sources and their nest by indirect communication among the ants, based on a chemical substance, called pheromone. The pheromone trails are kind of distributed numerical information which is reflect their experience accumulated while

LITERATURE REVIEW

Dantzig in 1975 introduced the name of the knapsack problem [9]. In simple terms, the classical knapsack problem aims to select the subset of items from a finite set of items, which maximizes a predefined objectives of the items chosen subject to constraint. The classical knapsack problem has been extended to different types of knapsack problems such as bounded, multiple-choice, quadratic knapsack problems, multi-dimensional, multi-objective, etc. Various algorithms have been developed to solve KP. These algorithms can be divided into two categories: exact algorithms, and heuristics or meta-heuristics. In terms of exact methods, Shih [19] proposed a linear programming based on branch-and-bound method. Thesen presented a recursive branch and bound algorithm [11]. Plateau and Elkihel proposed a hybridization of dynamic programming and branch-and-bound [12]. Due to NP completeness, these exact methods often fail in solving the problem with large number of variables [7]. Meta-heuristics on other hand have yielded very good results for solving KP. However, these algorithms have also a drawback that they can only find a near optimum solution. Example of this approach could include simulated annealing, tabu search, genetic algorithm [13-17]. Vasquez and Hao combined linear programming and tabu search [18]. Among various meta-heuristics algorithms that

exploring a particular problem [8]. Another information that ACO is used to construct a solution is the heuristic information. The heuristic information is problem-specific information, which means, different information from the problem could be used to improve approximate solution quality. In this paper, ACO algorithm is proposed to solve 0/1 knapsack problem. Then to improve approximate solution quality, a new heuristic information is proposed based on problem-specific knowledge.

The reminder of this paper is organized as follows: Section 2 reviews various algorithms that developed to solve KP. In Section 3, the mathematical formulation of KP is presented. Section 4 illustrates the proposed ACO approach for KP with different types of heuristic information. In Section 5, computational experiment results over some of generated test problems are given. Finally, the conclusion is summarised in Section 6.

are developed to solve the 0/1 KP, ant colony optimization (ACO) seems to be one of the best methods pointed out in the literature. ACO is a population-based approach which has been successfully applied to several NP-hard combinatorial optimization problems. Early applications of ACO algorithms into KP was [19-20]. Several extensions to the popular ACO optimization were developed in the last two decades. Fidanova [8] proposed different types of heuristic information. Alaya et al. presented different procedure where the pheromone trails laid in all edges instead of laid on the edges of visited paths [21]. Zhao et al. combined inner mutation and outer mutation with ACO algorithm [22]. Kong et al. proposed binary ant system (BAS) where the pheromone laying method was designed for the binary solution structure [23]. Ke et al. proposed a local search procedure to improve the solutions constructed by ants [6]. From a methodology point of view, the most relevant to the present paper is,

where in this work an additional heuristic information is proposed to improve the capable of obtaining high-quality solutions for KP [8].

PROBLEM FORMULATION

The 0/1 knapsack problem can be describe as follows: Suppose C is the maximum allowable weight of the container. A set of N boxes where each box jj has a profit p_{jj} and a weight w_{jj} . The problem is to pick a subset of boxes $S \subseteq N$ and pack them into a container such that their overall profit $P(S)$ is maximized, while the overall weight does not exceed a given allowable weight of the container. The mathematical formulation of the problem is given by:

$$\text{Max } \sum_{jj=1}^S p_{jj} x_{jj}, \quad (1)$$

$$\text{s.t. } \sum_{jj=1}^S w_{jj} x_{jj} \leq C, \quad (2)$$

$$x_{jj} \in \{0,1\}, \quad jj = 1,2, \dots, S$$

The assumptions can be stated as follows:

1. Each box jj has a profit $p_{jj} > 0$ and a weight $w_{jj} > 0$.
2. Container has a weight limit $C > 0$.
3. The summation of all boxes weight exceeds the allowable weight of the container ($\sum_{jj=1}^N w_{ii} > C$).
4. Weight distribution and numbers of boxes in the container is neglected.
5. Each box has same dimensions (i.e. width, height and depth).

ACO FOR 0/1 KNAPSACK PROBLEM

Because of its superiority of solving several complicated combinational optimization problems, such as travel salesman problem, quadratic assignment problem, and job-shop scheduling, this paper adapts ACO to solve the 0/1 knapsack problem [24]. For solving 0/1 knapsack problem using ACO, the key point here is to decide which components of the constructed solutions should be rewarded, and how to exploit these rewarded when constructed a new solution. At each cycle t , for a given ant k , the selection process of the next box b_{jj} from a set of candidate boxes is based on the probability $P_k^t(b_{jj})$ which depends on the value of the pheromone and the value of the heuristic information of the box as follows:

$$P_k^t(b_{jj}) = \frac{\tau_k^t(b_{jj})^\alpha \times \eta(b_{jj})^\beta}{\sum_{jj \in allowed_k^t} \tau_k^t(b_{jj})^\alpha \times \eta(b_{jj})^\beta} \quad (3)$$

where $\tau_k^t(b_{jj})$ is the pheromone factor of the box (b_{jj}) for ant k at iteration t , $\eta(b_{jj})$ is the heuristic information of the box (b_{jj}) . α and β are two parameters that determine the relative importance of these two factor.

$allowed_k^t \subseteq N - S_k^t$ is the set of remaining feasible boxes for ant k at iteration t . Thus, the higher value of $\tau_k^t(b_{jj})$ and/or $\eta(b_{jj})$, the more profitable it is to include box b_{jj} in the partial solution S_k^t . The pheromone factor

$r_k^t(b_{jj})$ evaluates the learned desirability of adding box b_{jj} to subset S_k^t based on two main strategies [25]:

1. The first one is to associate a pheromone trail r_{jj} with each object $jj \in N$, so that r_{jj} represents the learned desirability of selecting object jj in to the partial solution $S_{.k}^t$
2. The second one is to associate a pheromone trail r_{iijj} with each pair of different objects $(ii, jj) \in N$, so that r_{iijj} represents the learned desirability that objects ii will be more likely to be selected if object jj is already selected in the partial solution $S_{.k}^t$.

Table 1. ACO algorithm

Input: 0/1 knapsack problem parameters (p_{ij} , w_{jj} , and C) ACO Parameters (t , k , ρ , α , β , and QQ)
Initialize: Set an initial value of pheromones (i. e. $r^k(b_{ii}) = 1$) Select type of heuristic information $\eta\eta(b_{ii})$
Repeat: For $t = 1$ to number of iteration For $k = 1$ to number of ants For $n = 1$ to number of boxes Select b_{ii} to be in S_k^t based on probability $P_k^t(b_{ii})$ Check the b_{ii} not selected before Check the weight constrains of $S_k^t \leq C$ Calculates profit S_k^t End n End k Updates best solution Calculate L_k for the best solution Update pheromone trail $r^{t+1}(b_{ii})$ End t
Output: Print the best solution found

In this paper, first strategy is used. This mean, the pheromone trail is laid on each box in the set N . As a result, boxes with a higher trail level are more profitable. A data structure, called tabu list $tabu_k^t$ is also associated with each ant k in order to prevent an ant from choosing a box more than once (i.e. $tabu_k^t$ maintains a set of boxes that are included in the partial solution S_k^t). At the end of each cycle t , each ant k has constructed a solution and the pheromone is update. The pheromone trail r_{ii} for each box is updated in two steps. First, all pheromone evaporates according to the relation:

$$r^{t+1}(b_{ii}) = (1 - \rho)r^t(b_{ii}) \quad (4)$$

where $0 < \rho < 1$ is the evaporate rate. Then, the pheromone value of the ants that was associated with the good or promising solution is increased by $\Delta r_{ii}(t)$ as follows:

$$r^{t+1}(b_{ii}) = (1 - \rho)r_{ii}(t) + \Delta r_{ii}(t) \quad (5)$$

where the increment in the pheromone deposited on the best ant is taken as:

$$\Delta r_{ii}(t) = \begin{cases} G(L_k), & \text{if } b_{ii} \text{ associated with the good or promising solution} \\ 0, & \text{otherwise} \end{cases} \quad (6)$$

Usually, $G(L) = \frac{QQ}{L}$ for minimization problem, where QQ is a constant, L is the best value of the objective

function obtained by the k^{th} ant. However, for maximization problem the term $G(L_k) = \frac{QQL_k}{k}$. Further, the heuristic factor $\eta\eta(b_{ii})$ is to evaluate the promise of box b_{ii} based on the problem information. Fidanova [8] proposed two types of heuristic information. This paper introduce a new heuristic information. The three types of heuristic information that are considered in this paper will be presented in the next subsection. The proposed ACO algorithm for solving KP is present in Table 1.

Heuristic1: using only profit

The first type of heuristic uses only profit of the boxes. In this case, the heuristic information is calculated as follow:

$$\eta\eta_{jj} = p_{jj} \quad (7)$$

Based on this approach, the boxes with greater profit will be more desirable regardless its weight and the ratio of its weight to the total weight. This type will be called as a *Heuristics1*.

Heuristic2: using the profit to weight ratio

The second type of heuristic uses profit to weight ratio of the boxes. In this case, the heuristic information is calculated as follow: $\eta\eta_{jj} = \frac{p_{jj}}{w_{jj}}$ (8)

Based on this approach, the boxes with greater profit to weight ratio will be more desirable regardless of its weight to the total weight ratio. This type will be called as a *Heuristics2*.

Heuristic3: using the profit to weight ratio with capacity constraint

The third type of heuristic is a new heuristic which is proposed in this paper, this approach uses profit to weight ratio of the boxes in addition to total allowed weight of the container to weight of the box ratio. In this case, the heuristic information is calculated as follow: $\eta\eta_{jj} = \frac{p_{jj}}{w_{jj} \times W_{max}}$ (9)

Based on this approach, the boxes with greater profit to weight ratio and less capacity will be more desirable. This type will be called as a *Heuristics3*.

EXPERIMENT RESULTS

The algorithm that is given in Table 1 is coded on Matlab R2014a. Zhao et al. used data that are generated randomly for w_{ii} and p_{ii} . Based on this approach, this paper tested the three proposed algorithm by set of 4 0/1 knapsack problems [22]. The problems are generated randomly by the computer. The value of w_{ii} and p_{ii} were generated as integer numbers drawn from the discrete uniform generator $U(0, 100)$. The maximum weight of

the container was assumed to be third of the total weight of each case ($C =$ assumed as follows:

1. Number of iteration t is set to be 100.
2. Number of ants k is set to be 50.
3. Pheromone evaporation rate ρ is set to be 0.5.
4. The two relative importance factors α and β are set to be 1.

5. The constant QQ is set to be $2 \cdot N_{jj}=1$ (3000). The parameters of ACO are

For every experiment, results are obtained by performing 10 independent runs.

Table 2. Experimental results of different heuristics and n number of boxes

Boxes number n	Heuristic 1			Heuristic 2			Heuristic 3		
	Best	Average	Std. dev.	Best	Average	Std. dev.	Best	Average	Std. dev.
50	1359	1338	14.81	1551	1529	14.12	1564	1547	14.10
100	2524	2502	12.82	2836	2815	12.54	2928	2908	12.30

150	3617	3599	13.78	4327	4302	13.85	4455	4435	13.14
200	4574	4550	15.71	5353	5325	15.11	5642	5624	14.79

Table 2 shows the number of boxes n , the best value that is achieved by each ACO algorithm for the 10 independent runs, the average value that is achieved by each ACO algorithm for the 10 independent runs, and the standard deviation of the 10 independent runs. The bold numbers means the best average results that are achieved for each problem. It can be concluded that the proposed algorithms with *Heuristics3*, which utilises profit to weight ratio of the boxes in addition to the ratio of the total allowed weight of the container to the weight of the box, achieves better result in terms of best and average results for all tested problem as shown in Table 2 [26-29].

CONCLUSIONS

Picking and packing problem arises in logistics and production scheduling applications. A great deal of work has been done in order to develop algorithms for solving the picking and packing problems. Knapsack problem is a special case of the picking and packing problem. This paper presents a new heuristic information that incorporates with the ACO algorithms to handle the knapsack problem. The new heuristic information utilises

profit and weight of the boxes, and weight constraint of the container as a problem-specific knowledge to influence the convergence of ACO to best solutions. Numerical simulations show that using profit to weight ratio associated with the ratio of the total allowed weight of the container to the weight of the box in the heuristic information improved ACO in terms of better convergence efficiency and higher solution precision. This paper has been proven that full benefit of the problem-specific knowledge has impact on improve the quality of the solution. The paper can be extended by considering other constraints such as the volume of the container and/or weight distribution in the container.

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