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A Local search algorithm for the Mixed Capacitated Team Orienteering problem

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***Abstract*— Mixed Capacitated Team Orienteering Problem extends the classical Team Orienteering Problem by considering the profit of each node and arc with capacitated vehicles. More precisely, it consists of maximizing the sum of collected profit by a fixed number K of vehicles with capacity constraint, visiting each client at most once. In this paper, we propose a mathematical model and we developed a Local Search algorithm for the Mixed Capacitated Team Orienteering Problem with improvement algorithms.**

***Keywords*— Team Orienteering Problem, capacity constraint, Local Search algorithm, improvement algorithms.**

I. Introduction

During the last decade, many problems have been modeled as VRP where the objective is to minimize the cost of each tour. The problem presented in this paper extends of VRP with profit treating the capacity constraint. It's named the Mixed Capacitated Team Orienteering Problem (MCTOP), it aims to find the subset of visited nodes and arcs that maximize the total collected profit under capacity constraint for each vehicle.

II. Literature Review

Butt and Cavalier [1] were the first who introduced the Team Orienteering problem as the Multiple Tour Collection Maximum Problem. Team Orienteering originates from the sports game of orienteering. Each member of a competitor team (2, 3 or 4 members) armed with compass and map, starts at a specified control point, tries to visit as many other control points as possible within a prescribed time limit, and returns to a specified control point. Each checkpoint has a certain score and the objective is to maximize the total collected score. Chao et al. [2] defined the TOP in this context. Several heuristics are developed to solve this problem among them a tabu search heuristic developed by Tang and Miller-Hooks [3]. In 2006, Boussier et al. [4] developed an exact algorithm for the TOP. The most recent metaheuristics presented by Archetti et al. [5], Ke et al. [6] and Vansteenwegen et al. ([7], [8]). The TOP is treated with an additional constraint which is the capacity constraint whence the Capacitated Team Orienteering Problem (CTOP) where a subset of the potential customers has to be selected in such a way that the constraint of capacity Q of each vehicle is satisfied. In addition, the duration of the route of each vehicle does not exceed a time limit T_{max}. Archetti et al. [9] studied the CTOP and solved it by two variants of a Tabu search algorithm and a variable neighborhood search algorithm.

Gavalas [10] developed the Mixed Team Orienteering Problem with Time Windows (MTOPTW) for the case of windy graphs and present the first algorithmic approaches for the problem.

In this paper, two additional constraints have been added to the basic problem TOP: firstly, the profit in the arc where the MTOP and secondly the capacity constraint so the MCTOP.

III. Description Problem

The Mixed Capacitated Team Orienteering Problem (MCTOP) is the extension of the MTOP for the case of multiple vehicles under capacity constraint. The MCTOP aims to maximize the sum collected profit by a fixed number K of vehicles under capacity constraint for each vehicle. Each tour

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starting in d_e and ending at the final deposit d_s, with associated profit to the nodes and arcs.

Gavalas et al. [10] proved that the TOP is an NP-hard problem so the MCTOP is also hard.

Figure (1) shows an illustration of the MCTOP.

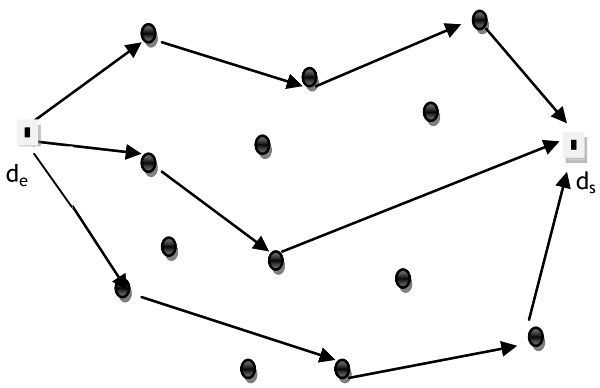

Fig1. Illustration of the MCTOP

We consider a directed graph *G (V, A)*, where *V* the set of vertex *V= 1,.,.n* and *A* is the set of arcs such that:

A = {(i, j)\ i Є C U {d_e}, j Є C U {d_s}, i≠j}.

We define:

c_{ij}: cost each arc *(i, j)*

t_{ij}: travel time between *i* and *j*

s_{ij}: the service time between nodes *i* and *j*.

p_{ij} : the profit in a profitable arc *(i, j) Є E*

d_{ij}: the demand in an arc *(i ,j)*

We consider a non-negative profit p_i associated with each visited vertex only once and the profit will be collected by one vehicle when the demand d_i is satisfied. Also, we noted the service time in the node *i* in the tour by s_i and the position of vertex *i* in the tour *k* by u_{ik}.

Two decision variables are used, the first y_{ik} equal 1 if the vertex *i* is included in the tour *k* and 0 if not. The second x_{ij} equal 1if the arc *(i, j)* is included in the tour *k*, 0 otherwise.

The mathematical model of the MCTOP is presented as follows:

$$Max \sum_{k=1}^{K} \left(\sum_{i=2}^{N-1} P_i . y_{ik} + \sum_{i=1}^{N-1} \sum_{j=2}^{N} P_{ij} . x_{ijk}\right) \quad (1)$$

subject to

$$\sum_{k=1}^{K} \sum_{j=2}^{N} x_{d_e jk} = \sum_{k=1}^{K} \sum_{j=1}^{N-1} x_{jd_s k} = K \quad (2)$$

$$\sum_{k=1}^{K} y_{jk} \le 1 \quad ; \forall j=2,...,N\text{-}1 \quad (3)$$

$$\sum_{i=1}^{N-1} x_{ijk} = \sum_{z=2}^{N} x_{jzk} = y_{ik} \quad ; \forall j=2,...,N\text{-}1, \forall k=1,...,K \quad (4)$$

$$\sum_{i=1}^{N-1} s_i y_i + \sum_{i=1}^{N-1} \sum_{j=2}^{N} (t_{ij} + s_{ij}).x_{ijk} \le T_{\max} \quad ; \forall k=1,...,K \quad (5)$$

$$\sum_{i=1}^{N-1} d_{ik} + \sum_{j=2}^{N} d_{ijk} \le Q_k \quad ; \forall k=1,...,K \quad (6)$$

$$2 \le u_{ik} \le N \quad ; i = 2,...,N \; ; k=1,...,K \quad (7)$$

$$u_{ik} - u_{jk} + 1 \le (N-1)(1 - x_{ijk}) \quad ; i, j = 2,...,N ; i \ne j \; ; k=1,...,K \quad (8)$$

$$x_{ijk} \in \{0,1\} \quad ; i, j = 1,...,N \; ; k=1,...,K \quad (9)$$

$$y_{ik} \in \{0,1\} \quad ; i = 1,...,N \; ; k=1,...,K \quad (10)$$

The objective function (1) is to maximize the total collected profit on the nodes and arcs for all tour. Each tour starts by the deposit d_e and finished in deposit d_s which are guaranteed by the constraints (2). The constraints (3) and (4) ensure respectively that each node is to visit only once and the connectivity for each tour. Constraints (5) you cannot exceed the limited time T_{max}. Constraints (6) ensure that the quantities delivered by each vehicle do not exceed its capacity. Constraints (7) and (8) are necessary for the elimination of sub-tours with u_{ik} the position of vertex *i* in the tour *k*. Finally, (9) and (10) are the binary constraints.

IV. Local Search algorithm for the MCTOP

The choice of the method Local Search (LS) is justified by two arguments: algorithm using a very little memory and can often find reasonable solutions in large state spaces. The goal of the LS is to find a solution with max objective value.

This method consists of two main steps: the initialization solution then improvement such as relocating a customer to a new position in a route or by removing edges from the solution and replacing them with new edges. Among the algorithms of RL, we chose that of Hill Climbing.

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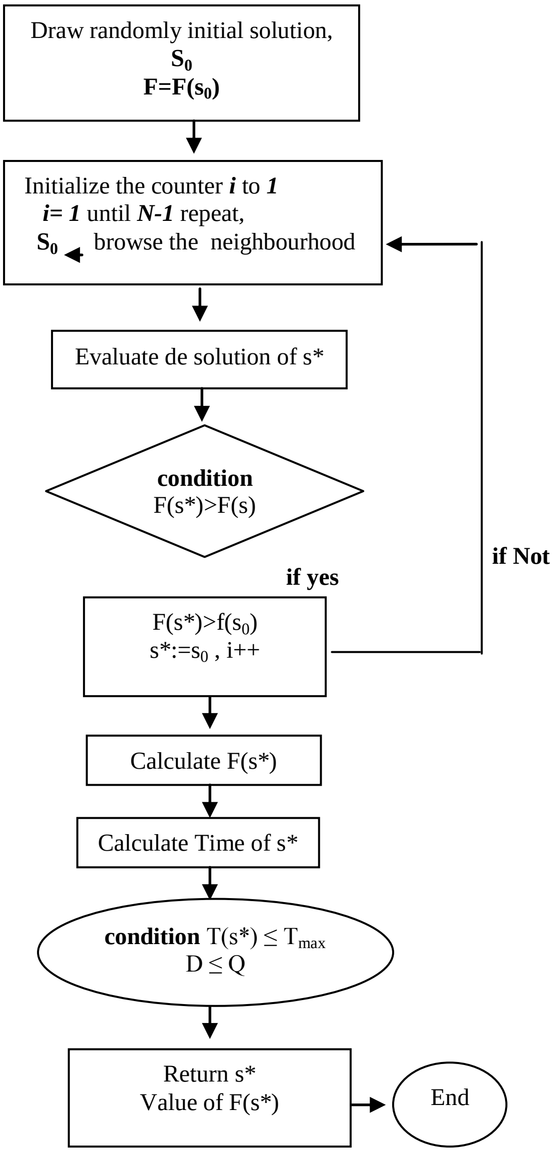
A. *The Hill Climbing Algorithm*

The Hill Climbing (HC) consists of choosing the neighbor of the current solution having the best quality (exhaustive exploration of the neighborhood). The steps of algorithm HC are presented below.

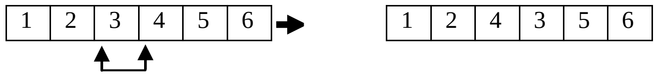


This algorithm obtained the first solution which will be improved using three improvement algorithms.

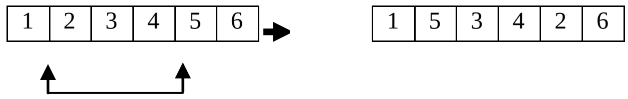
B. *Improvement algorithms*

Three algorithms are used for improving the initial solution: the insertion, permutation, and displacement.

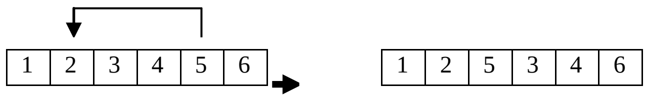
- Inversion: n-1 possible movements. It's to change the order of two adjacent nodes



- Permutation: n. (n-1)/2 possible movements. It is the act of randomly switch nodes and sees all possible moves.



- Displacement: n. (n-2) +1 possible movements. It consists to change the position of the node and inserting it in another order.



V. EXPERIMENTATIONS AND RESULTS

Our model is applied to a case of commercial Tunisian company. We carried out 5 tests which consist of increasing each time the number of served customers until 100 and in parallel the T_{max} to determine the optimal tour for each test. These tests are subdivided into two groups: for the test (10), (20) and test (30) are related to local customers, and for the test (50) and (100) represents the located customers in different cities. It was also mentioned that the test number reflects the number of customers for the test (10) and so forth for other tests. We fixed a number of vehicles, $K = 3$.

Table (I) summarizes the different results for all the tests obtained by applying the method of Hill Climbing with the algorithms of improvement.

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TABLE I
BEST OBTAINED SOLUTION BY THE THREE ALGORITHMS

Number of customers	K	F(x)		
		Inversion	Permutation	Displacement
10	1	875.45	956.59	890.12
	2	498.11	534.38	490.41
	3	-		
20	1	4111,93	3987.35	3872.07
	2	1389,22	1567.61	1432.11
	3	645.16	729.98	589.43
30	1	7694,04	7856.53	6821.97
	2	6410.03	5341	5776.34
	3	2014.11	2395.44	2412.87
50	1	9649.72	9329.67	8287.99
	2	6013.20	5893.87	5763.12
	3	4741,52	4906.34	4987.31
100	1	10189.45	11231.83	10654.19
	2	6567,23	6721.80	5890.43
	3	4715,17	4772.67	3950.45

The improvement algorithms could increase the solutions compared to the ones found in the initial heuristic of Local search.

The permutation procedure marked superiority for the majority of cases. This improvement has also led to an increase in the time of the tour, but still less than T_{max}.

The first tour has the highest values of F(x) since they target the most profitable subset according to the characteristics of the problem.

IV. CONCLUSIONS

In this work, we introduced the first model of the Mixed Capacitated Team Orienteering Problem (MCTOP), according to our knowledge, it's an extension of the MOP to multiple vehicles which the objective is to maximize total collected profit in nodes and arcs under the constraint of capacity for each vehicle. Since the MCTOP is an NP-hard problem, we presented the first heuristic to tackle it. The Local search heuristic is developed for solving the MCTOP using the algorithm of Descent. Next, three algorithms of improvement are used for the initially obtained solution.

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