Optimization of Waste Collection in Bamako by Tabu Search Algorithm

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Abstract: ***The problem of waste collection is a problem of optimizing vehicle routing in order to meet the needs of freight transportation between suppliers and customers. It involves designing a set of circuits, starting and returning from the same repository, through a set of pre-defined collection points for waste (customer or nodes). We propose an approach based on tabu search to minimize the total cost of transportation which is proportional to the total distance. Then we tested the efficiency of the algorithm under the Matlab R2014a solver and campare this result with the actuel data of Ozone Mali.***

Keywords: collection waste vehicle routing with times tabu search

1. Introduction

Interest in the waste sector continues to grow and becomes an environmental, economic and social problem, directly related to consumption patterns and to society in general for all and in particular to the Bamako City Council, which is responsible for collecting waste and transport. The field of waste collection is very vast, that is why we rely on the real data of Ozone Mali to be able to work on real problems [1] and to have a concrete application to our study. We are interested in the logistics part and more specifically in the collection and transport of waste from transit depots to the Noumoubougou disposal depot located 60 km from Bamako. The problem studied belongs to the family of vehicle routing problem (VRP) [2], which are extensions of the problem of the commercial traveler (TSP) [3].

The objective of VRP resolution is to design a set of routes, starting and returning from the same repository and passing through a set of points (often named customers) predefined. Each crossing point must be visited but each of them will be visited by only one tour. The optimization criterion generally concerns the total distance traveled by the vehicles. The optimization criterion generally concerns the total distance traveled by the vehicles, but other criteria can also be met.

In this article, we take into account the temporal aspect of the VRP, called the VRPTW problem. The vehicle routing problem time windows is a difficult combinatorial optimization problem.

The basic problem is that of the VRP which is added a constraint on the schedule of passage to certain nodes. These time constraints translate limits on the arrival date at the earliest and the start date at the latest at certain nodes of the network. This extension represents many concrete cases of management of vehicle tours.

In the literature, this problem is treated in two ways, either considering that the time windows are strict and must therefore be absolutely respected, either considering that the time windows are flexible and can therefore not be respected. Late penalties are usually associated with the cost function, which translates into non-compliance with these windows. In the problem studied here we consider that time windows are flexible.

The main objective of the problem studied is to minimize the total distance traveled by the vehicles. We use tabu search method in this work to solve the problem of garbage collection in Bamako, which is a problem of vehicle tour with windows of time. This article is divided into five parts, the first part is devoted to the introduction and the literary review, and the second part of the article is devoted to the presentation of the collection problem. We present the mathematical model to minimize the transport cost of waste collection, then the method of resolution based on the tabu search adapted to problem was presented. We tested our algorithm by the Matlab R2014a solver to see the efficiency of the program, and finally the article ends with a conclusion.

2. State of the Art

The problem of optimization of waste collection has appeared in research in recent years, particularly with the emergence of the consideration of environmental constraints. The various existing works are intended to enable organizations in charge of this management to limit costs while ensuring a good quality of service and while limiting environmental impacts.

The problem of optimizing the collection of waste is quite recent but has already given rise to many studies [4]. Most of the articles in the literature focus on a real problem and aim at a concrete application to be put in place at the end of the study. They have a great practical interest for implementation, but often include specificities that are specific to each problem studied. The studies are based on two types of modeling: the one based on the VRP or the one based on the CARP. If it seems more natural to model the collection of household waste using a CARP type graph (since door-to-door collection is often done on a street). This modeling has been less developed in favor of a more aggregated type of. The classic objectives of waste collection are to minimize the number of vehicles required for this collection, to minimize the total collection time or the total distance traveled by the vehicles [5]. Without pretending to be exhaustive, we present below various collection optimization studies of which we are aware.

In his paper, Kim et al. [6] in 2006, propose to study the elaboration of collection circuits based on the Solomon insertion method taking into account four objectives: the two classic objectives of waste collection are the minimization of the number of vehicles and minimizing total travel time. He also adds a goal of compactness of the tours and balance between these tours; these latter objectives being processed using an algorithm based on the grouping of capacity. In this study, the authors also take into account the break time of ripper drivers. The authors Nuortio et al. [4] developed a metaheuristic applied to waste collection in Finland, based on local search methods and other metaheuristics in which acceleration and memory reduction methods were added. Lacomme et al. [7], in 2006, propose to study waste collection for the city of Troyes using Arc Routing Problem and solves this problem using an evolutionary algorithm that takes into consideration two objectives, minimizing the total distance and minimizing the largest tour.

In 2007, Kim et al. [8] consider the problem deterministically and stochastically. They have developed two versions of algorithms to handle each type of problem and show that their algorithms are efficient and improve the results given by more conventional methods. In 2008, Bautista et al. [9] are continuing a study started in 2004 [10], and are using a method based on ant colonies to manage waste collection in a part of Barcelona. This method is combined with a construction heuristic and a local search.
All of these articles demonstrate the needs of cities to improve the performance of their collection system and the effort to solve these various practical problems. However, although some constraints are common and present in the majority of articles, many constraints come directly from the field and are very often specific to a study. This is why it seems difficult to directly transpose a method of resolution from one case to another and to generalize these methods. In all of these studies, we have found that the cost objective is predominant, it is the essential element to build tours. We will try to minimize the total cost of transportation of the collection which is proportional to the total distance traveled by the vehicles.

3. Presentation of the problem

Our problem emerges from waste collection problems in the district of Bamako. As the number of household's increases, the waste generated also increases, in order to maintain the quality of the environment, the waste generated must be properly collected. As a reminder, in the city of Bamako, each inhabitant produces about 1kg of waste per day. The management of these wastes is done at two levels, the primary collection or pre-collection provided by the Economic Interest Group which using trucks, tow carts and tricycles, pick up waste at the gates of the concessions for them deposit at the level of transits deposits.

At this first level, it is the GIEs that provide this primary management and in the context of decentralization the first responsible is the Mayor of the municipality. The secondary collection is provided by the Highways and its partner Ozone Mali. Thus, it is Ozone Mali which transports the waste of the points of transit, towards the final discharge of Noumoubougou or final deposit.

Despite the fact that several players have been on the ground, namely the informal, the Economic Interest Group, Ozone Mali, the result remains insufficient. This poor waste management has consequences for wastewater when it is known that rainwater managed by collectors is only used for drainage. It should be noted that Bamako produces more than 1600 tons of household waste per day and only 40% of this waste is evacuated by Ozone-Mali. This proves that the city is far from clean. The difficulties in collecting waste in Bamako are due to the allocation of limited financial resources and also the problem of transport route. There is less of an optimal route for trucks to make their tours of the city to the final depot, which is 60 km from the city. This study will therefore make it possible to manage the waste issue more optimally.

The strong constraints of the system are:
- Pass all collection points,
- Maximum number of vehicles per collection day,
- Maximum tonnage of the truck not to be exceeded
- Maximum working time.

4. Mathematical model

Our objective is to serve all garbage collection requests, minimizing the total cost of transportation. This cost is relative to the**.** The problem is characterized.

The precise problem that we seek to solve is that presented by (Fisher et al) [11; 12] the formulation of the mathematical model is based on a directed graph: G = (V, A) where:
- $V = (v_0, v_1, \dots, v_{n-1})$is the set of n vertices (nodes) of the graph representing the set of clients, with,$v_0$representing the repository;;
- $A = \{(v_i, v_j) / v_i, v_j \in V; i \neq j\}$is the set of oriented arcs representing the path between the two vertices.

The parameters of the problem:
- $k = \{1, \dots, m\}$: all available vehicles;
- Q the ability to collect on a node v_i;
- q_i the ability to collect on a node nœud v_i ;
- d_{ij} the travel distance of the arc (v_i, v_j).
- $[a_i, b_i]$: the time window associates with the node v_i with $a_i$the arrival date at the earliest in the nodev_j et $b_i$representing the end date of service at the latest for the node v_i ;
- t_i : the service time of the node v_i ;
- t_{ij} : the transport time of the node $v_i$to the node v_j ;
- u_i^k : the temporal decision variable

- representing the arrival time of the vehicle $k$in the node v_i ;
- M : a great value.

The decision variables used are

- $y_i^k = 1$ if the node i is visited by the vehicle$k$ et 0 otherwise..
- $x_{ij}^k = 1$if the arc $(i,j)$is in the vehicle tour k and 0 otherwise

The objective function:

$$Minimiser\ f = \sum_{i\in Z}\sum_{j\in Z}\sum_{k\in K} x_{ij}^k d_{ij} \dots\dots\dots \quad \dots \quad .(1)$$

$$\sum_{i=1}^{n} q_i y_i^k \le Q\ (k = 1,\dots,m) \dots\dots\dots\dots\dots\dots\dots\dots (2)$$

$$\sum_{k\in K} y_i^k = 1\ \ (i = 1,\dots,n) \dots\dots\dots\dots\dots\dots\dots\dots\dots (3)$$

$$\sum_{k=1}^{m} y_i^k = m \quad (i = 0) \dots\dots\dots\dots\dots \quad (4)$$

$$\sum_{i\in V} x_{ij}^k = y_j^k (j = 0,\dots,n-1);\ \ (k = 1,\dots,m) \dots \quad (5)$$

$$\sum_{i\in V} x_{ij}^k = y_i^k (i = 0,\dots,n-1);\ \ (k = 1,\dots,m) \dots \quad (6)$$

$$\sum_{ij\in X} x_{ij}^k \le |X| - 1\ \ (\forall X \subset V),\ \ (k = 1,\dots,m) \dots \quad (7)$$

$$x_{ij}^k \in \{0,1\} (i,j = 0,\dots,n-1; i \ne j); \dots\dots\dots\dots \quad (8)$$

$$y_i^k \in \{0,1\} (i = 0,\dots,n-1); (k = 1,\dots,m) \dots\dots \quad (9)$$

$$y_i^k \le u_i^k \le b_i (i = 0,\dots,n-1); (k = 1,\dots,m) \dots \quad (10)$$

$$u_i^k + t_i + t_{ij} - M\left(1 - x_{ij}^k\right) \le u_j^k (i = 0,\dots,n-1) ..(11)$$

$$\sum_{i}^{n} t_i y_i^k + \sum_{i=1}^{n}\sum_{j=1}^{n} x_{ij}^k t_{ij} \le T\ \ (k = 1,\dots,m),\ \ (j \ne i)(12)$$

This mathematical model expresses the fact that one seeks to determine a set of tours while minimizing the total distance traveled (1). The constraint (2) expresses that the capacity of the vehicle must be respected. Constraints (3) and (4) express the fact that a node is visited by a single vehicle, the depot is visited by all vehicles. Constraints (5) and (6) establish that a vehicle visiting a collection node leaves it to visit another node. Constraint (7) states that all tours must be related and from the depot. The binary of the decision variables is given by the constraints (8) and (9). The constrain (10) makes it possible to verify that the nodes are collected in their respective time window for a given vehicle. The constraint (11) expresses the succession between the collection of two vertices v_i *and* v_j : if v_j is collected after v_i by the same vehicle k then the start of the collection v_j can not be done until the collection of v_i is complete and until the path between these two nodes has been completed. Taking into account a limit on the duration of each tour (that is to say a working time), noted T can be done by introducing the constraint (12).

5. Methodology

We present the approach based on tabu search algorithm to minimize the total cost of transport. The tabu search method is a combinatorial optimization technique designed to solve the problem of trapping in the local minima of the objective function. It was formalized in 1986 by F. Glover [13] and, independently, under a different name, but it originates from previous concepts (in the field of artificial intelligence), including ideas developed by F. Glover [13]. The principle of this research is very simple. In a basic stochastic search, initial solutions must be generated and then modified randomly using modification operators called disturbance operators. The new generation solutions are called neighbors. Suppose we seek to minimize a function $f(x)$the characteristics of a taboo search are summarized in the following algorithm: Starting from a solution s at the iteration k, we define a neighborhood V^* in the neighborhood of $N(s)$, according to the history already conducted. The choice of sub-neighborhood aims to avoid an exploration of an area that is too big, impractical or too expensive in time. The best solution s^* is computed in V^*, and becomes the current new solution. When no movement improving the current solution is possible, the risk of visiting the previous solution and more generally creating cycles is present. It is therefore important to prohibit movements leasing to recently visit solutions which can be done by removing these neighborhood solutions from s. More generally, the neighborhood of s will depend on the track followed, which we will note $N(s,k)$ The exclusion of solutions can be done through one or more tabu lists that keep in memory the latest solutions encountered or features common to them.

5.1 Tabu search algorithm

Step 1

Initiation:

s_0 Initial solution

$$s \leftarrow s_0, s^* \leftarrow s_0, c^* \leftarrow f(s_0)$$
$$T = \emptyset$$

Step 2

Generate a subset of solution in the vicinity of s

$s' \in N(s)$ Tel que $\forall x \in N(s), f(x) \ge f(s')$ et $s' \notin T$

if $f(s') < c^*$ so $s^* \leftarrow s'$ et $c^* \leftarrow f(s')$

Update T

Step3:

If the stop condition is not satisfied return to step 2.

5.2 Tabu search algorithm Adaptation of tabu research to the problem of waste collection

We use the nearest neighbor heuristic to determine the initial (turned) solution of our problem, then the 2-opt method will be used to generate the neighborhood of the initial solution.

5.2.1 Initial solution

It is determined from the deposit, then we visit the nearest vertex of the deposit and repeat the process until all summits are visited and we can return to the starting vertex. A locally optimal decision is made at each step of the algorithm.

5.2.2 Generation of the neighborhood of the initial solution

Let s be the solution of the problem posed represented by the tour t. Neighboring solutions are generated using the 2-optimality method, which consists of removing two non-adjacent arcs from a tour, and then reconnecting the two chains obtained by two new arcs to reform the cycle.

5.2.3. The Tabu list

It is very expensive in terms of memory space to keep all the solution we want to make taboo. For this reason, it is necessary to minimize the size of the taboo list. For this, we introduce a taboo list that will be constructed in the following way.

When two arcs (a; b) and (c; d) undergo an interchange, we introduce the element (a, c, b, d) in the taboo list. We will say that the transformation of the two arcs of the tour is taboo if the element (a, c, b, d) is in the taboo list.

5.2.4 Stopping criterion

The process stops after a number of successive iterations performed without performing a minimization of the objective function or when the fixed maximum iteration number is reached.

5.2.5 Application of the tabu search algorithm to the problem studied

We apply the algorithm search tabu to network composed of ten node geographically distributed. We reported the distances between the deposit and the nodes and between them matrix.

Initiation

Initial solution:

Let s_0 be the initial tour determined by the nearest neighbor method

s_0 : 0-4-1-5-3-7-2-6-8-9-0 total cost 140.

The tabu list is empty:$T = \emptyset$

Neighborhood Generation of s0

The 2-optimality method is applied to the initial tour s_0 and the size of the taboo list is set to 4 elements, then the maximum number of iterations is 7, that is, the process is stopped after 7 iterations.

Itération1:

Two arcs are non-adjacent if they have no vertex in common.

Non-adjacent arcs of the initial tour : (4,1) et (5,3) ; (1,5) et (3,7) ; (5,3) et (7,2) ; (3,7) et (2,6) ; (7,2) et (6,8) ; (2,6) et (8,9)

0-4-1-3-5-7-2-6-8-9-0 de coût =145

0-4-1-5-7-3-2-6-8-9-0 de coût=140

0-4-1-5-3-2-7-6-8-9-0 de coût=144

0-4-1-5-3-7-6-2-8-9-0 de coût=137 s_1^*

0-4-1-5-3-7-2-8-6-9-0 de coût=150

Taboo list:T

4	5	1	3
1	3	5	7
5	7	3	2
7	6	2	8

From this iteration, one checks if the modification m is tabu or not and one continues the generation of the neighborhoods.

Iteration 2 :

$s_1^* \leftarrow s_0$, $s_1^* \in V(s_0)$ <=> $\min V(s_0) = s_1^*$

s_1^*=0-4-1-5-3-7-6-2-8-9-0 de coût=137

Determination de min$V(s_1^*)$

The non-adjacent arcs are : (4,1) et (5,6) ; (1,5) et (3,7) ; (5,3) et (7,6) ; (3,7) et (6,2) ; (7,6) et (2,8) ; (6,2) et (8,9)

$\min V(s_1) = s_2^*$= 0-4-1-5-7-3-6-2-8-9-0 de coût 137

The modification $m = (5,7,3,6) \notin L$ donc on met à jour la liste taboue.

1	3	5	7
5	7	3	2
7	6	2	8
5	7	3	6

Iteration 2

$s_2^* \leftarrow s_1$, $s_2^* \in V(s_1)$ <=> $\min V(s_1) = s_2^*$

s_1^*=0-4-1-5-3-7-6-2-8-9-0 de coût=137

Determination of min$V(s_2^*)$

Non-adjacent arcs are: (4,1) et (5,6) ; (1,5) et (3,7) ; (5,3) et (7,6) ; (3,7) et (6,2) ; (7,6) et (2,8) ; (6,2) et (8,9)

$\min V(s_1) = s_2^*$= 0-4-1-5-7-3-6-2-8-9-0 de coût 138

The modification $m = (5,7,3,6) \notin T$ so we update the tabu list.

1	3	5	7
5	7	3	2
7	6	2	8
5	7	3	6

This procedure is continued in the same way until one of the stop criteria is verified.

$c(s^*) = \min(c(s_1), c(s_2), \ldots, c(s_{10}))$therefore$s^* = c(s_3) = 133$

6. Numerical results

In this part we present the results obtained by our resolution approach on a Bamako waste collection network. The data used in this document were collected during one week from Ozone Mali. This situation concerns 25 nodes spread over different locations and 3 vehicles ensure the collection. We present the result obtained by our approach of resolution and we will compare this result with that of the company Ozone. The numerical test was done on the Matlab R2014a solver. The results are in the following tables.

Table 1: Result obtained by the tabu search

Vehicle	Tour
1	[0-22-21-4-5-10-15-19-23-13-0]
2	[0-20-8-11-9-3-7-4-16-24-0]
3	[0-18-1-10-2-6-12-0]
Cost	601 km

Table 2: Actual Result for Ozone Mali

Vehicle	Tour
1	[0-13-8-4-15-19-23-22-5-10-0]
2	[0-9-21-16-24-11-9-20-7-0]
3	[0-3-12-18-2-1-6-13-0]
Cost	803 km

As we can see in both tables, the total distance traveled by Ozone is 803 km, this solution is improved by the tabu search algorithm with a percentage of (803-601) * 100/803 = 25%

This reduction in the distance traveled reduces the amount of fuel used by the vehicle and thus benefits Ozone Mali. More traveling less causes less wear of the vehicle used, which is still profitable for business. We assumed that the time windows were flexible. It should be noted that 75% of the nodes were collected in the time allotted and the remaining 15% represents the time of the deposit.

7. Conclusion

A search algorithm to solve the waste collection problem with time windows was developed in two stages.Initially, an initial solution satisfying both the capacity and time window constraints was generated. Then to improve this initial solution, taboo research was applied.This algorithmic process refined all of the acquired rounds to obtain an optimal distance. The algorithm was applied to a 25-node sample of the Solomon reference problem. The results obtained show that the optimal solution is lower than the actual solution of Ozone Mali. With good tour planning Ozone waste collection can save a lot of money.

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