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Tabu Search Algorithm to Solve the Intermodal Terminal Location Problem

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Abstract. Establishment of appropriate terminals is effective as the main gate entrance to international, national and local transportation network for economic performance, traffic safety and reduction of environmental pollution. This paper focuses on intermodal terminal location problem. The main objective of this problem is to determine which of the terminals of a set of candidate terminals should be opened such that the total cost be minimized. In this problem, demands of customers will ship directly (without the use of terminals) between the origin and destination of customers, or intermodaly (by using two terminals) or even by combination of both methods. Since this problem is NP-hard, metaheuristics algorithms such as tabu search (TS) is used to solve it. The algorithm is compared with greedy randomized adaptive search procedure (GRASP) on instance of this problem. Results show the efficiency of TS in comparision with GRASP.

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1. Introduction

Location is one of the most important branches of operational research that leads to reduction of air pollution and successful of industrial units. Alfred Weber [15] introduced location theory in 1909, when he locates a single warehouse for minimizing the total distance between the warehouse and customers. In 1965, Hakimi [7] determined the optimum location of switching centers in a communication network. Terminal creation is always required for many investments. If the location of terminals not selected correctly, it may increase economic, pollution and traffic costs. So managers should attempt to choose appropriate location for terminals. Carbon dioxide is one of the factors that contribute to air pollution. Transportation sector generates about 30% of carbon dioxide released into the environment. Specially road transportation generates about 71% of the total of gas emitted by the transportation sector [5]. So, road transportation has the most pollution to other modes of transportation (rail, marine, etc). Statistics show that society needs Serious Decision to reduce the transportation effects on the environment. Multimodal transportation is one of the methods to approach this goal. It is defined as the transportation of goods by a combination of at least two modes of transport, without a change of container for the goods [13]. Intermodal transportation is a particular type of multimodal transportation. In this paper we focus on intermodal terminal transportation.

Bontenkoning et al. [3] stated that intermodal research is emerging and could be a research field in its own right. Their paper along with the work presented by Macharis and Bontenkoning provide extensive reviews of literature in the area of intermodal terminals. The location of terminals is one of the most success factors bearing directly and indirectly on the main stakeholders (e.g. Terminal operators, freight operators, local communities, investors and policy makers) involved. Bostel and Dejax [4] proposed a mathematical model to minimize container handling at a rail-rail transfer terminal. A linear programming model for the intermodal container terminal introduced by Holguin and Jaras [9]. In 1998, Kraman et al. [16] proposed a probablistic model of port intermodal terminal. This model determines the optimum placement of containers on an origin train, destination train and in short-term storage. Southworth and Peterson [12] used a geographic information system (GIS) technology for modelling of large multi-modal freight networks. Verma et al. provided a bi-objective model for planning and managing rail-truck intermodal transportation of hazardous materials [14].

In this paper, Determining the appropriate locations for intermodal terminals is the main objective. For reaching this purpose, a set of points as a candidate is considered for openning terminals that are determined by experts and GIS methods.

Arnold et al. [1] presented a model for the intermodal terminal location in 2004. In this paper this model for formulation an ITLP is used. This model is easy and understable. Arnold et al. presented a paper as a simulation tool for combined rail road transport in intermodal terminals[10]. They solved the intermodal terminal location problem by branch and bound procedure [2]. But this method is not suitable for a problem of a large size. So a metaheuristic method to solve this problem is used. Sorenson et. al used efficient algorithm such as ABHC and GRASP to solve ITLP [11]. In this paper tabu search algorithm to solve this problem is usedto solve this problem.

The remaining of the paper is organized as follows: In Section 2 the intermodal terminal location problem is surveyed. Section 3 presents a mathematical model for this problem. A tabu search algorithm is developed in Section 4. Finally Sections 5 and 6 represent numerical results and conclutions respecting.

2. The Intermodal Terminal Location Problem

An intermodal freight terminal is defined as a location equipped of transfer between different modes. Intermodal transport of goods using two modes of transport simultaneously, where one (passive) means of transport is carried on another (active) means of transport which provides traction and consumes energy, e.g. Rail/road transport, sea/road transport and sea/rail transport [13]. An excellent example of an intermodal transportation network is transportation network of containers. This

problem was introduced by Arnold et al. [1], in which they propose mixed integer programming model that minimizes the total cost, where the cost is consisted of unimodal and intermodal transportation costs and fixed terminal location costs. This model is proved in [11] as a NP-hard problem.
A graphical represention for a simple problem with customers and 2 terminals that demand between them is shipped by rail road terminal by intermodally or unimodally is shown in Figure 1. The dashed line shows the demands between customers (origin-Destination) shipped directly by truck, however bold lines shows demands transported intermodally (by road-rail).

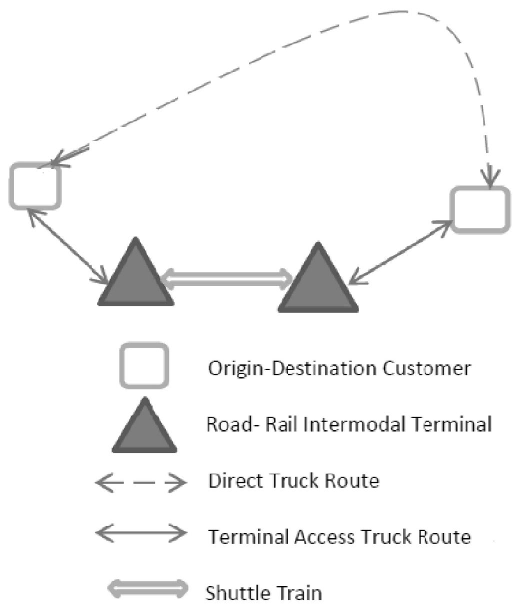

Figure 1. Rail-Road Intermodal Terminal

3. Mathematical Model

The model described by Arnold et al. [2], is used in this work. The objective of this model is minimizing the total cost (cost of unimodally, intermodally and opening the terminals) by considering the Terminal capacity constraints and demand constraints. The model described mathematically as follows. ITLP is consist of a set of m potential sites where terminals be established and n customers whose demands can be transferd by using terminals or by unimodally or both of them. Let I denote the indices of all origion-destinitions, i.e, $I = \{1, 2, ..., n\}$ and K denote the indices of all candidate terminals, i.e, $K = \{1, 2, ..., m\}$ in the network. The cost of opening a terminal at a certain location k is given as the location cost(or fixed cost) F_k. The capacity of terminal K is indicated by C_k. The value of q_{ij} be a quantity of demands that shoud be shipped from customer(location or zones of activity) i to a customer j. The decision variable w_{ij} represents the fraction of demand q_{ij} transported unimodaly. However a decision variable x_{ij}^{km} related to the fraction of the demand q_{ij} transported intermodaly by using terminals $K, m \in K$. The values of decision variables y_k prescribe whether a terminal k is open($y_k = 1$) or closed($y_k = 0$). The value of c_{ij}^{km} is the unite cost of shipping demand between customer i to customer j through terminals K and m. c_{ij} is a unite cost of shipping demand directly from i to$j$.

$$\min : \sum_{i,j\in I} \sum_{k,m\in K} c_{ij}^{km} x_{ij}^{km} + \sum_{i,j\in I} c_{ij} w_{ij} + \sum_{k\in K} F_k C_k$$

$$s.t. x_{ij}^{km} \leqslant q_{ij} y_k \quad \forall k, m \in K \quad \forall i, j \in I \tag{1}$$

$$x_{ij}^{km} \leqslant q_{ij} y_m \quad \forall k, m \in K \quad \forall i, j \in I, \tag{2}$$

$$\sum_{k,m\in K} x_{ij}^{km} + w_{ij} = q_{ij} \qquad \forall i, j \in I, \tag{3}$$

$$\sum_{i,j\in I} \sum_{k,m\in K} x_{ij}^{km} + \sum_{i,j\in I} \sum_{k,m\in K} x_{ij}^{km} \leqslant C_k \ \ \forall k \in K, \tag{4}$$

$$w_{ij} \geqslant 0 \ \ x_{ij}^{km} \geqslant 0 \ \ x_{ij}^{km} = 0 \ \ \forall k, m \in K \quad \forall i, j \in I, \tag{5}$$

$$y_k \in \{0, 1\} \qquad \forall k \in K. \tag{6}$$

The objective function minimizes the total transportation cost associated with all transportation demands within the network. This cost is the

sum of the transportation cost by intermodaly, unimodaly and the total fixed cost associated with all open terminals in the network. A terminal should be opened for demands to be shipped through it (constraints (1), (2)). The total amount of demands for each origin-destinition-pair should be transportated intermodaly or unimodaly (constraint (3)). Demands can only be transported intermodaly through a certain terminal if its capacity is not yet reached (constraint (4)). Constraint (5) ensures that no demand is transported by using of only one terminal and the quantity of demands should be non-negative. Finally, constraints (6) indicate that a terminal is either open or close.
In order to approximate transportation cost associated with a specific set of open terminals, this paper uses a hueristic evaluation procedure [11]. This hueristic evaluation procedure allocates a flow of demand to either two terminals (intermodal flow) or directly between customer (unimodal flow). The main idea behind the hueristic is to give advantage to the origin-distinition-pairs that have the highest apportunity cost of not being allocated to their preferred route. In this hueristic, the regret calculates the cost difference between the route (i.e., pair of terminals) with lowest cost and that with the second lowest cost, for any pair of customers. The algorithm presented in [11] intend to allocate flows to the best route. If no intermodal route is possible; or if the cheapest possible terminal route is more expensive than unimodal route, the demands are transportated unimodaly.

4. Tabu Search for ITLP

TS metahueristic is a technique for solving combinational optimization problems that it was introduced by Glover in 1989 [6]. TS uses exploration and flexible memory to guide the search in the solution process. By exploration, it determines a search based on the properties of the current solution and the search history by repeatedly making moves from one solution to anothers that are located in its neighborhood. TS selects the best move based on evaluation function. This function chooses a solution that produces the best improvement or the least non-improvement in the objective function in each iteration. By memory, it uses short term and long term memory structures to keep a selective search history. These memories are designed to keep track of solution, as well as some of their attributes, visited in the search process. The short term memory (tabu list) records status change of terminals at recent time. The long term memories visited solutions and it prevents solution from being visited as well as, prevent repeatition and cycling. A pseudo-code description of the TS algorithm is given in Algorithm 1.

Algorithm 1 (TS)

`x` $\leftarrow$ *Find Initial Solution*()
  Tabu List$\leftarrow \oslash$
`reapet`
  $\hat{x} \leftarrow Best\ Move(N(x))$
`if` $\hat{x} \notin$ *Tabu List* `then`
  `x` $\leftarrow \hat{x}$
`elseif` $\in$ *Tabu List and Aspiration Critria met* `then`
  `x` $\leftarrow \hat{x}$
`else`
  Do not update `x`
`endif`
  Update Tabu List(x)
  `until` Stopping Criteria Reached

The components of TS hueristic procedure is introduced in the following sub-sections.

4.1 Move

For a given solution, suppose K_0, K_1 indicated the indices of terminals that K is partitiones into subsets K_0 and K_1, where K_0, K_1 contains the indices of the terminals that are open; respectively, i.e, $K_0 = \{k \in K \mid y_k = 0\}$ and $K_1 = \{k \in K \mid y_k = 1\}$. Accordingly, m_0 and m_1 indicate the numbers of closed and opened terminals; $m_0 =\mid K_0 \mid$, $m_1 =\mid K_1 \mid$, usch that $m_0 + m_1$ is equel to m. A move is defined as the status change of any terminals $k \in K$, i.e, $y_k \leftarrow 1 - y_k$. So a move is a passing from the current partition of K to a new partition of K by tracking one element from K_0 and placing it intoK_1 or vice versa. We use t to count the number of moves; or iterations. The minimum total cost; consist of the transportation cost (intermodal and unimodal transport cost) and the cost of opening terminal of the partition at iteration t is defined as f_k. The cost of the best solution found in the first iteration is defined by f_0 and the iteration at which f_0 found is denoted by t_0. The values of f_0 and t_0 are updated when a better solution is found and are reset at each iterations. The cost of the best solution found since the search started is indicated by f_{best}. The value of f_{best} is updated whenever the search is founded a solution with total cost less than f_{best}.

4.2 Search space and nieghborhood structure

The search space is the space of all possible solutions that can be visited during the search. for instance, in intermodal terminal location problem, the search space could simply be the set of feasible solutions to the problem, where each point in the search space corresponding to a vector with m-component that m is number of terminals. Each component of this vector indicates a state (open or close) of its corresponding terminal. At each iteration of tabu search, the local transformations is applied to the current solution, indicated by s, define a set of neighboring solution in the search space, indicated by N(s)(the neiborhood of s). Actually, N(s) is a subset of the search space that is included of solutions obtained by applying a single local transformation to s :

In general, for any problem, there are many more possible nieghborhood structures than search space definitions. In intermodal terminal location problem, the nieghborhood of feasible solution s_1 could be s_2 such that s_2 will get by changing single component of s_1. For example if we have 4 candidate terminals and s_1=(0 1 0 1) be a feasible solution then the nieghborhood of this solution will be (0 1 0 0), (0 0 0 1) and (0 1 1 1). This nieghborhood could be defined by hamming distance d, between solutions s_1 and s_2 is by form of follow:

$$d(s_1, s_2) = \sum_{k \in K} (y_k^{s1} - y_k^{s2})^2. \tag{7}$$

For each solution such as s_1, if $d(s_1, s_2)$ is equel to 1, then s_2 is defined as nieghborhood s_1. Figure 2 indicates the nieghborhood of solutions at the begining of solution (0 1 0 1). The nieghborhood of this point are (1 1 0 1), (0 1 0 0), (0 0 0 1) and (0 1 1 1). In the next iteration this solution move to a solution (1 1 0 1), becauce this solution has a less evaluation function value in comparision with the other nieghborhood of (0 1 0 1). According to tabu this move(i.e., change of first component) is keeping to tabu list for a time(length of tabu list).

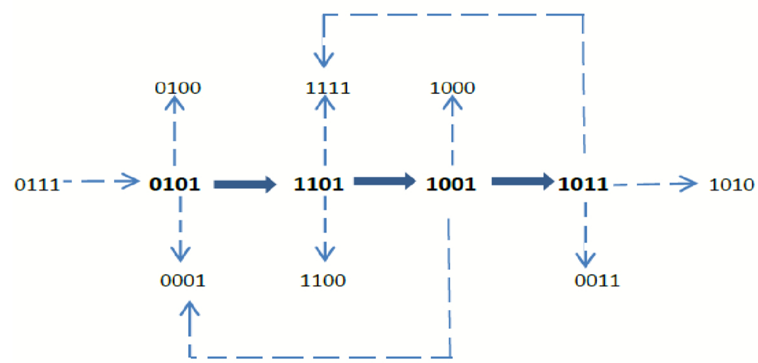

Figure 2. Nieghborhood of Solutions

4.3 Tabu list and aspiration criteria

In TS, tabus may prevent attractive moves, even when there is no danger cycling, or they may lead to an overall stragnation of the search procedure. Thus, it is necessary to use algorithmic devices that will allow one to cancel tabus. These are named aspiration criteria. The simplest and most commonly aspiration criteria, found in almost all TS implementions, allows a tabu move when it results in a solution with an evalution function value (objective value) better than a current best-known solution. The key rule is that if cycling can not appearance, tabus can be disregarded.

4.4 Stopping criteria

The most commonly used stopping criteria in TS are:

1) After a fixed number of iterations or fixed amount of CPU time;

2) After sum number of iterations without an improvement in the evalutionary function value;

3) When the objective value reaches a pre-specified threshold value.

5. Numerical Results

In this section some numerical examples and instances are used. In order to show the efficiency of TS algorithm this examples are solved and the result compared with Greedy Randomized Adaptive Search Procedure (GRASP) method [8].

5.1 Expremental setting

The introduced algorithm is encoded in MATLAB 7.8.0.347 (R2009b) on a standard DELL with 2.00 GHZ processor and 6.00 GB RAM and tasted on the generated ITLPs. Each introduced algorithm has been done 20 times for each instance of ITLP. The stop condition for the algorithms is maximum iteration number that is N=100. The mean value and Standard deviation is computed for 20 implemention of each algorithm with the CPU running time algorithm.

5.2 Performance study

To generate an instance, at the first, the number of customers and the number of candidate terminal locations in the intermodal network, are determined. For each customer i and terminal k, coordinates (x_i,y_i) and (x_k,y_k) are randomly generated in the Euclidean square between (0,0) and (x_{max}=10000,y_{max}=10000). The mount of demands q_{ij} to be transported between each pair of customers (i,j), ($i \neq j$) is randomly generated in the interval [0,500]. The fixed F_k and capacity C_k of each terminal k are randomly get from the intervals [0, C_{max} = 10000] and $[0,F_{max} = 500000]$ respectively. This random data has the value of $c_{ij}(i \neq j)$ is equal to the Euclidean distance between customers i and j. To determining c_{ij}^{km}, the direct distance between customer i and the departing terminal are summed up, the distance between the two terminals and the distance between the receiving terminal and customer j. Then this sum divided by two. The tabu list lengh is set $\frac{N}{\mid k \mid}$ such that K is the number of candidate terminals. we solve the generated instances of this problem by TS. The results of this algorithm and GRASP algorithm are indicated in Tables 1 and 2. In these tables c and t indicate customers and terminals respectively. The performance mean time is measured in seconds. This results shows TS has performance of quality solutions and run time respected to GRASP better.

Table 1: Compution results for TS algorithm

c	t	*Mean value* $\times(10^7)$	*Standard deviation* $\times(10^7)$	*Mean CPU time* $\times(10^1)$
10	20	9.1456	1045362.100276	0.15
20	20	46.241	21789341.789321	.2
30	10	111.21	3560452.5345612	6.584
30	20	104.56	8910464.6511238	10.86

Table 2: Compution results for GRASP algorithm

c	t	*Mean value* $\times(10^7)$	*Standard deviation* $\times(10^7)$	*Mean CPU time* $\times(10^1)$
10	20	9.2352	105352.679376	2
20	20	46.457	2221461.78567	2.54
30	10	111.66	381546.5976512	8.45
30	20	104.44	9010463.786534	16.26

5.3 Statistical analysis of trials based on solution quality

In order to compare two algorithms on a dedicated lot of problem instances, one can use the performance of an algorithm to learn if its result delivers better quality than the solution produced by the other methods for the same problem instance. Hence, the performance is an important measure in optimization problems to determines the success probability of an algorithm. In other words, it determines the algorithm which produces better solutions. The wilcoxon rank sum tests are conducted between the quality of the solution of the proposed TS algorithm and the best results which found by the GRASP algorithms. This test is used to determine whether the proposed algorithm is better than the GRASP algorithms or not. The results of the 10 test runs for TS and GRASP algorithm are used. For two algorithms A and B the distribution of their results are compared using the null-hypothesis $H_0 : F_A = F_B$ and the one-sided alternative $H_1 : F_A < F_B$. We performed the test at a significance level of $\alpha = 0.05$. The proposed algorithms statistically have better performance than GRASP algorithm, if the p-value between their results is smaller than significance level. This value show that proposed TS algorithm has statistically better performance with 95% certainty than GRASP algorithm.

Assume that the results of the TS and GRASP are given for 10 runs on four test case. Test cases are performanced on 10 customer -10 terminal, 20 customer -10 terminal, 30 customer -10 terminal and 30 customer -20 terminal respectively. First, we rank all the observations in ascending order. The smallest value has rank 1, the second smallest rank 2, and so on. The sum of ranks for TS solutions will be T=74.

So, the p-values for this test is $P(Z < -2.343) = .0096$. Since this p-value is smaller than α, we would reject the hypothesisH_0 and conclude that the distribution of the TS results is to the left of the results of the GRASP algorithm. In other words, the hypothesis H_0 is rejected while H_1 hypothesis is accepted. Hence, we can say that TS has better performance than GRASP algorithms. Result of Wilcoxon rank sum tests for TS algorithm on four test case are given in Table 3 that value of 1 shows successful of TS in comparision with GRASP and 0 shows failur of.

Table 3: Result of wilcoxon rank sum tests for TS on 4 test case

Test Case(TC)	TC1	TC2	TC3	TC4
Wilcoxon rank sum tests for TS	1	0	1	1

6. Conclutions

In this paper, we deal with intermodal terminal location problem (ITLP). The objective of this problem is to determine which of a set of candidate terminal locations to be used and how to route the supply and demand of a set of customers through the network to minimize the cost. Since the ITLP is a NP-hard problem, therefore, this problem is solved with TS metahueristic algorithm. Numerical results on some randomly generated ITLPs confirm the efficiency of a tabu search algorithm in both computing time and quality solutions in camparsion to greedy randomized adaptive search algorithm. Further research has been identified throughout this work, as follows: (i) using other metaheuristics and hybrid algorithm for solving this problem and (ii) incorporating variants such as stochastic or fuzzy are another future research.

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