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A METAHEURISTIC-BASED VEHICLE ROUTING FOR INTRACITY CONTAINER TRANSPORTATION

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Abstract. *In seaport cities, a large number of containers are transported between container terminals, intermodal facilities, off-dock container yards, and some other storage areas. The frequent container transportations within the city cause tremendous traffic and environmental problems. This paper addresses a vehicle routing problem for short-haul container transportations. We present a new routing algorithm where simulated annealing and tabu search algorithms are incorporated. The total travel time of all vehicles in operation is taken as performance criterion. Experimental results show that the new algorithm provides vehicle routes of good quality.*
Keywords: Container transportation, Vehicle routing, Simulated annealing, Tabu search

1. **Introduction.** As international trade volumes increase over time, container transportation plays an important role in logistics management. For import containers, the containers are discharged out of the container vessels, temporarily stored in the on-dock container yard, and then moved by container trucks to some other places such as off-dock container yards, rail stations, logistics centers, inland container depots and local coastal port yards. The flow of the export containers would be reversed. The frequent container transportations within seaport cities lead to traffic and environmental problems. This paper addresses vehicle routing problems for container transportation with the objective of minimizing the total travel time of the vehicles in operation.

There are a number of research works dealing with short-haul container transportation problems. The work of [1] presents a container shuttle routing procedure using an insertion algorithm. Given a planning horizon, they assign transportation jobs one by one to a vehicle. When the completion time of a vehicle is larger than a predefined planning horizon, an additional vehicle is introduced and the procedure is repeated. Recent papers add additional considerations in the container shuttle problems by considering empty containers [2,3], time windows [4,5], different vehicle types [6], different container sizes [7], and separable tractor-trailer mode [8-10]. Extensive literature list on container transportation operations can be found in [11]. This paper focuses on vehicle routing problem for the containers to be moved within a day whose destinations are predefined. For the system under consideration, [12] presents two-phase planning algorithm to find the minimum fleet size required and travel route for each vehicle within the planning horizon. In phase one, an optimization model is constructed to obtain a fleet planning with minimum vehicle travel time and to provide a lower bound of the fleet size. In phase two, a tabu search based procedure is presented to construct a vehicle routing with the least number of vehicles. This paper attempts to improve the work of [12] by incorporating tabu search and simulated annealing algorithms in the vehicle routing decision. In the previous work, the vehicle route is rescheduled only for the vehicle with the longest travel time. We believe this idea may lead to a solution with a local optimum too quickly. In addition, the previous work ignores the influence of the initial solution on the quality of the final solution. The new algorithm attempts to improve the routes for all vehicles first with several initial solutions and then balance the transportation loads among the vehicles.

The paper is organized as follows. Section 2 describes the vehicle routing problem for container transportation with a simple example. In Section 3, an improved vehicle routing procedure is presented where simulated annealing and tabu search algorithms are incorporated. Numerical results and some concluding remarks are given in Sections 4 and 5, respectively.

2. **Problem Statement.** The system under consideration is static in that the number of containers to be moved between two locations is known, and all the containers are ready to be picked up at the beginning of a day. The travel times between two locations are deterministic and known in advance. At the beginning of a day, the vehicles ready at a specific location (e.g., depot) leave for performing their transportation jobs and return to the depot after completing all the assigned jobs. A vehicle moves only a single container at a time. It is desirable to satisfy all the transportation requirements within a day (480 minutes) with the minimum number of vehicles and the least total travel time.

The travel time of a vehicle consists of loaded travel time and empty travel time. For a clear understanding, let us describe a simple container transportation problem shown in Figure 1, with four containers to be moved, three yards, one depot and a single vehicle. The numbers on the arrows in the figure indicate the number of containers to be delivered, and travel time in minutes between two stations. For example, one container is to be moved from station L1 to station L2, and two containers should be moved from station L2 to station L1, and the travel time between L1 and L2 is 25 minutes. Among many possible route alternatives, let us take two alternatives, R1: depot – L1 = L2 = L1 – L3 = L2 = L1 – depot and R2: depot – L3 = L2 = L1 = L2 = L1 – depot where '–' indicates empty vehicle travel, and '=' loaded vehicle travel. The total loaded travel distance is 95 minutes no matter which route plan is used, while the empty travel time is 70 minutes for alternative R1, and 50 minutes for alternative R2. Thus, the total travel time of the vehicle is 165 minutes in case of route R1 and 145 minutes in case of route R2.

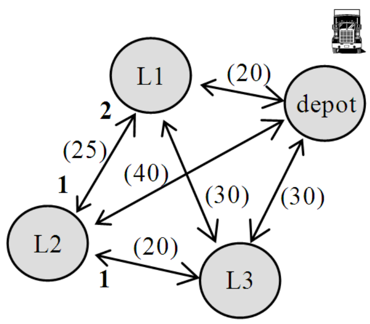

FIGURE 1. Container shuttle transportation

As seen in the example discussed above, the loaded travel time is constant with given transportation requirements. Then, the total travel time depends on empty travel time. Hence, minimizing total empty travel time is equivalent to minimizing total travel time. In the following section, a vehicle routing algorithm is presented to minimize total travel time (empty travel time).

3. **A Metaheuristic-Based Container Vehicle Routing.** It is known that the container shuttle problem discussed above is known as an NP-hard problem. Hence, heuristics are used to solve the container shuttle problem. The algorithm proposed by [12] utilizes

a tabu search to determine the routing for each vehicle with objective of minimizing total travel time subject to work shift condition. This paper improves their work by incorporating simulated annealing and tabu search algorithms in vehicle routing. Figure 2 shows the overall vehicle routing procedure presented in this paper. The route improvement is carried out with several initial solutions generated by a greedy algorithm. For internal route improvement for each vehicle, simulated annealing algorithm is used. Simulated annealing escapes entrapment at a local optimum by using a probability condition that accepts or rejects an inferior move.

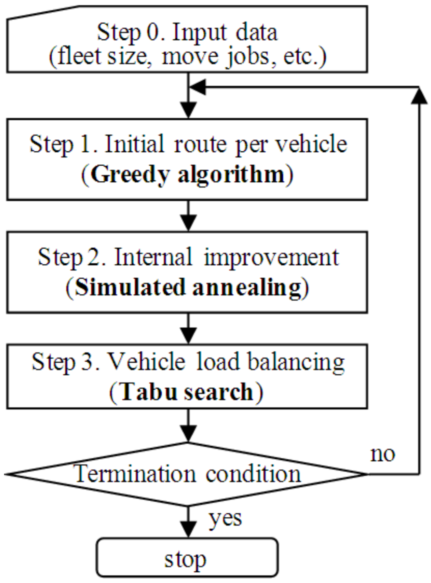

FIGURE 2. Proposed vehicle routing procedure for container transportation

A detailed solution procedure is described below after defining the notations used in the procedure.
v: number of vehicles.
$C(V_i)$: travel time for vehicle V_i to perform all the transportation jobs assigned to it.
$C_{new}(C_{curr})$: total vehicle travel time of the new (current) solution.
$M_{new}(M_{curr})$: makespan of the new (current) solution.
rand(): a random number between zero and one.
t_{xy}: empty travel time for picking up job y after completing job x delivery.
Step 0. The number of vehicles (v), container movement requirements with their origins and destinations, and travel times between two locations are given.
Step 1. An initial solution is generated by a greedy algorithm as follows.
G1: Choose v transportation jobs at random and assign them to each vehicle.
G2: Select a vehicle with the least $C(V_i)$.
G3: Select a container from the unassigned containers that yields the least empty vehicle travel time when it is appended to the route of the selected vehicle. Append it to the last job of the selected vehicle. Tie breaker is the longest-loaded-vehicle-time-first rule. This rule is selected because the longest processing time (LPT) rule is known to perform well in parallel machine scheduling for minimizing the makespan.
G4: Repeat G2 and G3 until all the transportation jobs are assigned.
Step 2. For each vehicle, the vehicle route is improved by a simulated annealing (SA) algorithm as follows.
S0: Set initial temperature T_0, temperature schedule parameter r, target accept-iteration t, and the number of temperature changes *iter*, $p = 0$, and $i = 0$.
S1: Generate neighborhood set by relocating one transportation job in the vehicle route.
$T = T_i$ (where temperature schedule $T_i = rT_{i-1}$ for $i \geq 1$).

S2: Select a neighbor randomly.
If $C_{new} < C_{curr}$, accept neighbor as current solution, go to S3.
else if $rand()$< $\exp(-(C_{new}C_{curr})/T)$
then accept the neighbor as current solution; go to S3
else go to S2

S3: $p = p + 1$.
If $p < t$, then go to S2,
else if $i <iter$, then $i = i + 1$, go to S1
else the current solution is the best for the vehicle and stop

Step 3. Based on the tabu search algorithm, the transportation loads are balanced among the vehicles as follows:

T1: Find a vehicle V randomly. Calculate $s_j = t_{ij} + t_{jk} - t_{ik}$ where jobs i, j, and k are consecutive jobs on the route of V.

T2: Select job j^* from V, where j^*=agr$_j$ max(s_j) and $j^* \notin TL$. Update the Tabu List, TL.

T3: Calculate the completion time of each vehicle in case that job j^* is assigned to the vehicle. Select the vehicle with the least completion time, and insert job j^* into the route of the vehicle. If $M_{new} \leq M_{last}$, then update the current solution with new solution.

T4: If stopping condition for tabu search is not met, then go to T1
else If stopping condition is met for the entire procedure, then stop the procedure.
else go to Step 1 and repeat the procedure.

In summary, with the input parameters given in Step 0, Step 1 generates an initial solution, and Step 2 improves the solution of Step 1 for each vehicle by using simulated annealing algorithm, and finally Step 3 improves the solution even further by balancing transportation workload of each vehicle based on tabu search algorithm. After Step 3, we will have a new solution. However, the quality of the solution may depend on the initial solution generated in Step 1 because the initial route is generated based on random assignment for the first move job for each vehicle. Hence, we perform the procedure above from Step 1 to Step 3 for predefined iterations and select one best solution among them.

4. **Numerical Experiments.**

To evaluate the performance of the proposed routing procedure, we perform numerical experiments with a sample problem adopted from [12]. There are one depot and six locations, location L1 to L6. The transportation requirements (and their loaded travel times) are as follows: L1→L4: 15 containers (40 minutes), L1→L5: 47(30), L1→L6: 2(30), L2→L4: 28(40), L2→L5: 5(35), L2→L6: 2(35), L3→L4: 22(10), L4→L1: 3(40), L4→L3: 10(10), L4→L6: 1(25), L5→L1: 21(30), L5→L3: 2(35), L6→L5: 48(5). The unit of time is the minute for the travel times. There are 15 vehicles responsible to complete all the transportation jobs.

The performance of the proposed heuristic (IST) is compared with the heuristic (INS) of [1], the heuristic (TBS) of [12] and greedy algorithm (GRD) adopted frequently in container transportation industries. Following parameters are decided by some preliminary experiments: tabu teneure = 2.0, the number of iterations (in TBS and IST) = 200, SA initial temperature = 3.0, SA schedule factor r = 0.9. Figure 3 compares the performance of the different routing schemes. It is seen that IST routing scheme provides good performance in terms of the total travel time while the GRD algorithm, widely used in industries, provides the worst result. The total travel time is reduced by about 10% by using IST algorithm instead of GRD algorithm.

Experiments are performed to examine the performance of the routing algorithms with different scenarios. All the scenarios have 21 pickup/delivery stations while each scenario has different transportation requirements from each other, ranging from 285 to 438 delivery jobs. The number of trucks in operation is between 17 and 24, depending on the

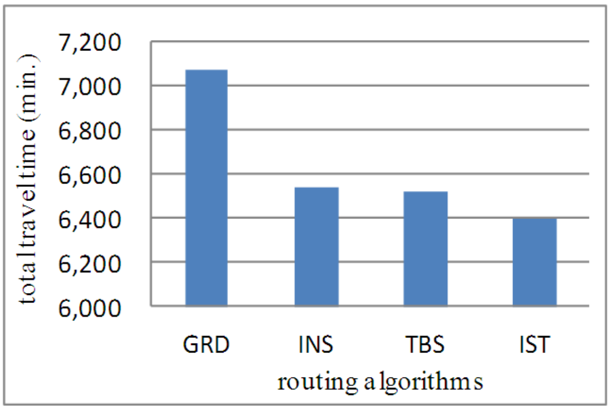

Figure 3. Performance of routing algorithms

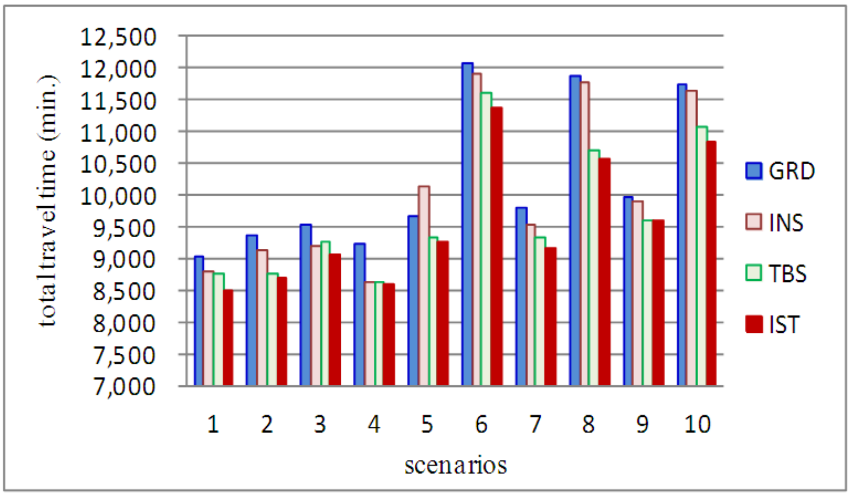

Figure 4. Comparison of routing algorithms for ten scenarios

transportation requirements. Figure 4 shows total travel time for each routing algorithm for ten scenarios. It is seen that the IST provides better performance for all scenarios.

5. **Conclusion.** This paper presents a container vehicle routing procedure for short-haul container transportations in seaport cities whose objective is to minimize the total travel time. The routing scheme improves the previous work of [12] where simulated annealing algorithm is used for efficient route for each vehicle and tabu search algorithm is used to balance the movement workloads among vehicles. The new algorithm has been compared with some existing vehicle routing algorithms with various scenarios. Experimental results show that the proposed model provides vehicle routing of good quality. There are a variety of container transportation environments that this paper does not cover, including the systems with different types of containers, relocation problems of empty containers, the problems associated with different types of vehicles, and time window restrictions. Future works may cover these problems.

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