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Vehicle Scheduling for Inland Container Transportation

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컨테이너 내륙 운송을 위한 차량 일정 계획의 수립

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The importance of efficient container transportation becomes more significant each year due to the constant growth of the global marketplace, and studies focusing on shipping efficiency are becoming increasingly important. In this paper, we propose an approach for vehicle scheduling that decreases the number of vehicles required for freight commerce by analyzing and scheduling optimal routes. Container transportation can be classified into round and single-trip transportation, and each vehicle can be linked in a specific order based on the vehicle state after completing an order. We develop a mathematical model to determine the required number of vehicles with optimal routing, and a heuristic algorithm to perform vehicle scheduling for many orders in a significantly shorter duration. Finally, we tested some numerical examples and compared the developed model and the heuristic algorithm. We also developed a decision support system that can schedule vehicles based on the heuristic algorithm.

Keyword: customer order type, vehicle state, linkage transportation

1. Introduction

The importance of container transportation is proportional to the constantly increasing amount of import/export freight from year to year. Numerous attempts have been made to improve the productivity of container logistics in order to increase the domestic and global competitiveness of trucking companies. The logistics industry is changing continuously due to deregulation, globalization, increasing business competition, development of telecommunication techniques, and new research findings that improve the transportation efficiencies and logistics costs.

The amount of worldwide container freight increased to 200 million TEU (Twenty-foot Equivalent Unit) in 2000, as compared to 90 million TEU in 1990. Based on the growth of trade, we expect that this amount will increase to 400 million TEU in 2010 (SERI, 2003). Hence, the amount of container freight will increase continuously due to the increasing competitiveness arising from advancements in logistics. Effectively dealing with this increased container traffic is an urgent problem for container transportation systems. In order to solve this problem, we need to study inland transportation to improve the efficiency. With regard to national freight transportation rates from 2005 to 2006, the rates of

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road and railroad transportation increased by 7.0% and 11.7% (9.04 million TEU and 1.07 million TEU in 2006), respectively, while freight rates of marine transportation decreased by 38.3%. (168,000 TEU in 2006). This implies that the national dependence on inland transportation has increased (KITA, 2007). This has also led to an increasing number of empty transportation vehicles and competition for general freight transportation. Therefore, it is necessary to conduct research directed toward decreasing the number of empty vehicles and increasing the efficiency of inland transportation.

The operation and design problems related to container transportation are very complicated as a variety of factors such as coverage areas, container size, container type, and transportation type, must be considered. This study proposes an approach that determines the required number of vehicles and their scheduling for inland container transportation.

Previous studies on inland container transportation aimed to establish transportation scheduling that minimized the total transportation distance and the time taken by the container vehicles to satisfy the customer requirements. Minimizing the total transportation distance or times is equivalent to minimizing the total number of vehicles used. Most of the studies progressed to vehicle routing problems and vehicle scheduling problems. Cullen *et al.* (1981) and Dumas *et al.* (1991) considered time windows as typical studies. Along with container vehicle transportation, Crainic *et al.* (1993) and Yun *et al.* (1999) dealt with transportation problems to minimize the number of empty containers. Kim *et al.* (1997) proposed a vehicle allocation solution and system that is based on a dispatching rule that considers time windows. Ko *et al.* (2000, 2002) proposed a search solution that is based on an insertion heuristic and mathematical model to determine the number of vehicles required for container shuttle transportation. Koo *et al.* (2003) dealt with vehicle routing problems based on a Tabu search.

Most studies on container traffic also deal with the management and design of container terminals. However, one study of container transportation alone is not sufficient. Due to the importance of container transportation, additional studies are required in this field. The scheduling problems of container vehicles are complex because it is necessary to consider not only the quality and quantity factors, which draw upon the experience of the dispatching manager, but also several other factors such as the container size, container type, and transportation type. This study focused on reducing the workload of the dispatching manager using a decision support system based on a developed heuristic algorithm.

This paper proposes a method to minimize the number of container vehicles required in inland container transportation by dividing inland container transportation into round-trip and single-trip transportation in order to approach realistic container transportation scheduling. Round-trip and single-trip transportation will be explained in the next section.

We use the following assumptions:
① The demand for customer orders is known.
② The first starting point and last arrival point have only one depot.
③ All orders are completed in one day.
④ One route is serviced by one vehicle.
⑤ We consider 20-ft and 40-ft containers.
⑥ We only consider dry containers.
⑦ The direction of the container door is not considered.
⑧ The speed of all vehicles is the same.
⑨ The number of vehicles is unlimited.
⑩ There exist only combined vehicles that, at a given time, can load either two 20-ft containers or one 40-ft container.

1.1 Round-trip transportation

Inland container transportation is divided into two types, namely, round-trip and single-trip transportation, based on the customer order. Round-trip transportation uses only one container from the starting point to the arrival point. The customer order for import requires the import freight to be unloaded from the import container, while that for export requires the export freight to be loaded into the empty container. In other words, the import container, shown in <Figure 1>, is loaded in the depot and then transported to the customer. The import container becomes an empty container after unloading the contents to the customer. The empty containers are returned to the depot or are transported to the other customers who require them.

The round-trip transportation of an export container involves loading export freight in the empty container, transporting it from the depot or another customer, and returning it to the depot. After unloading the import freight from the container, the container can be linked with another customer order for export through round-trip transportation. The import container of a customer becomes an empty container after unloading the freight and can then be transported to the depot or to another customer. If the other customer has an export order, the empty container can be used for transportation. However, the other customer must be located within an area where transportation is available. After loading the export freight in the empty container, the container is returned to the depot as an export container.

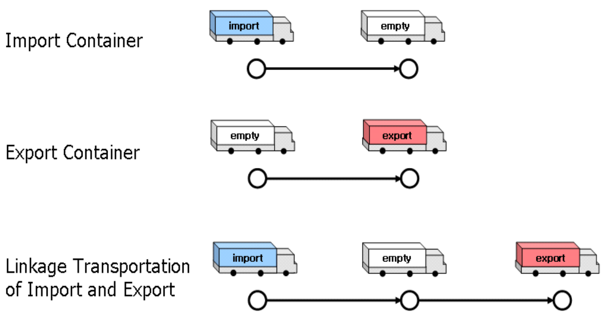


Figure 1. Round-trip transportation of the import and export container

1.2 Single-trip transportation

Single-trip transportation involves loading the export and empty containers or unloading the import and empty containers. In other words, the single-trip transportation of an import container, as shown in <Figure 2>, involves loading the import container in the depot and then unloading it as per customer request, after which the vehicle becomes an empty vehicle. The single-trip transportation of an export container involves loading the customer's export container onto an empty vehicle.

In single-trip transportation, apart from loading or unloading the empty container, linkage transportation with another single-trip transportation is also possible, as shown in <Figure 2>. If the import or empty container is unloaded to the customer, the vehicle becomes an empty vehicle and is then available for loading an export or empty container. In addition, the empty container can be linked to other customers on the round-trip transportation route for export.

A vehicle is comprised of the trailer and chassis. In this paper, we do not consider the case in which we return only with the trailer after delivering both the chassis and container to the customer. We also do not consider the case in which we start with only the trailer and deliver both the chassis and container to the customer. These cases are not suitable for linkage transportation with other customer orders for round-trip and single-trip transportation and therefore they are not mentioned in this paper.

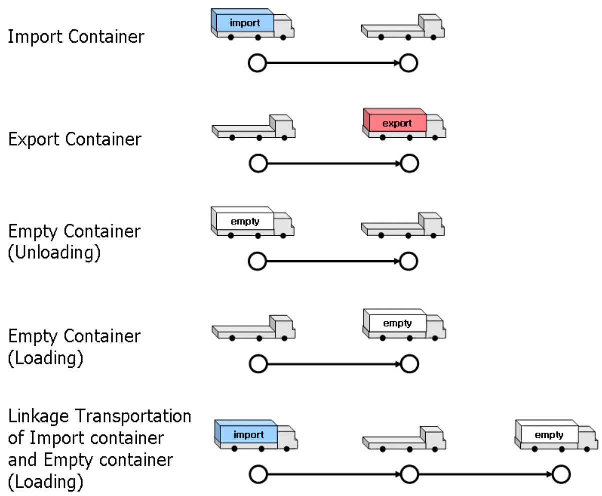


Figure 2. Single-trip transportation of the import, export and empty container

The rest of this paper is organized as follows. We develop the mathematical model for minimizing the required number of container vehicles in section 2. We present the developed heuristic algorithm in section 3 and present numerical examples for the mathematical model and heuristic algorithm in section 4. In section 5, we present a decision support system based on the heuristic algorithm. The conclusion is presented in the final section.

2. Mathematical model

The following notations were used as follows:

Notations:

- $i,\ j,\ c$: index for customers ($i, j, c = 0, 1, \cdots, n$)
- k : index for vehicles ($k = 1, 2, \cdots, K$)
- y : index for order types ($y = 1, 2, \cdots, 12$)
- l : index for vehicle states after completing an order ($l = 1, 2, \cdots, 6$)
- q_i : request time of customer i
- v_i : service time of customer i
- w_i : freight weight of customer i
- t_{ij} : transportation time from customer i to customer j
- MT : available transportation time among customers

MH : available waiting time from arrival time to request time of customer
MW : available weight of each vehicle
M : big M

Decision variables:
x_{ijk} : 1, if a container for customer j is transported from customer i by vehicle k
0, otherwise
R_{ijkyl} : 1, if a container for customer j with order type y and state l is transported from customer i by vehicle k
0, otherwise

In this paper, the starting time of customer i is obtained by adding the service time and request time of customer i. The arrival time after transporting from customer i to customer j is obtained by adding the starting time and transportation time. The waiting time after arriving at customer j is obtained by subtracting the arrival time and request time of customer j. The available time of each vehicle is not considered since container transportation scheduling is performed based on the customer request time. The order type y and vehicle state l will be explained in the next section.

2.1 Order types and vehicle states

Table 1. List of customer order types

index (y)	transportation type	container size	task type
1	round-trip	40-ft	import container
2	round-trip	20-ft	import container
3	round-trip	40-ft	export container
4	round-trip	20-ft	export container
5	single-trip	40-ft	import container
6	single-trip	20-ft	import container
7	single-trip	40-ft	export container
8	single-trip	20-ft	export container
9	single-trip	40-ft	empty container (unloading)
10	single-trip	20-ft	empty container (unloading)
11	single-trip	40-ft	empty container (loading)
12	single-trip	20-ft	empty container (loading)

In this section, we classify customer orders into 12 types based on the customer requests, as shown in <Table 1>.

Container transportation divides the customer order types into round-trip and single-trip transportation. Round-trip transportation can be used to unload import freight from and load export freight into the container. Single-trip transportation can be used to unload (or load) import (or export) containers and empty containers, and either 40-ft or 20-ft containers are used. The constraints in this paper are as follows:
① The weight of a container loaded in a vehicle is within the available weight.
② The transportation time between customers using each vehicle is within the available transportation time.
③ The waiting time after transportation between customers is within the available waiting time.

Table 2. List of vehicle states after completing an order

index (l)	container size	vehicle state after completing an order
1	40-feet	export container
2	20-feet	export container
3	40-feet	empty container
4	20-feet	empty container
5	40-feet	empty vehicle
6	20-feet	empty space

<Table 2> lists the vehicle states that can be generated after completing a customer order. If a vehicle undertakes a customer order with a 40-ft import container through round-trip transportation ($y = 1$), the vehicle state after order completion is an empty container ($l = 3$). Similarly, if a vehicle undertakes a customer order with a 20-ft import container through single-trip transportation ($y = 6$), the vehicle state after order completion is an empty space ($l = 6$). A vehicle can load two 20-ft containers and thus one space is available after completing one customer order. Therefore when it performs the order type corresponding to each customer order, it can determine the next customer order which is most practically linked by the vehicle state. If a vehicle is loaded with a 40-ft export container or two 20-ft export containers, the vehicle must return to the depot. Hence, the vehicle cannot link with another customer order. The order types that can be linked based on the vehicle

Table 3. Order types that can be linked based on the vehicle state

vehicle state	l	order type that can be linked	y	vehicle state after order	l
40ft empty container	3	40ft export of round-trip 40t empty container (unloading)	3 9	40ft export container empty truck	1 5
20ft export container 20ft empty container 20ft empty space	2 4 6	20ft import of round-trip 20ft export of round-trip 20ft import of single-trip 20ft export of single-trip 20ft empty container (unloading) 20ft empty container (loading)	2 4 6 8 10 12	20ft empty container 20ft export container 20ft empty space 20ft export container 20ft empty space 20ft empty container	4 2 6 2 6 4
20ft export container/empty container 20ft empty container/empty container	2/4 4/4	20ft export of round-trip 20ft empty container (unloading)	4 10	20ft export container 20ft empty space	2 6
20ft export container/empty space	2/6	20ft export of single-trip 20ft empty container (loading)	8 12	20ft export container 20ft empty container	2 4
20ft empty container/empty space	4/6	20ft export of round-trip 20ft export of single-trip 20ft empty container (unloading) 20ft empty container (loading)	4 8 10 12	20ft export container 20ft export container 20ft empty space 20ft empty container	2 2 6 4
empty vehicle 20ft empty space/empty space	5 6/6	40ft export of single-trip 20ft export of single-trip 40ft empty container (loading) 20ft empty container (loading)	7 8 11 12	40ft export container 20ft export container 40ft empty container 20ft empty container	1 2 3 4

state are summarized in <Table 3>.

An example of linkage transportation with round-trip and single-trip transportation is shown in <Figure 3>. This example shows that seven customer orders can be transported using two vehicles by a connectable type with time windows. We want to establish vehicle scheduling using linked transportation and minimize the number of vehicles required

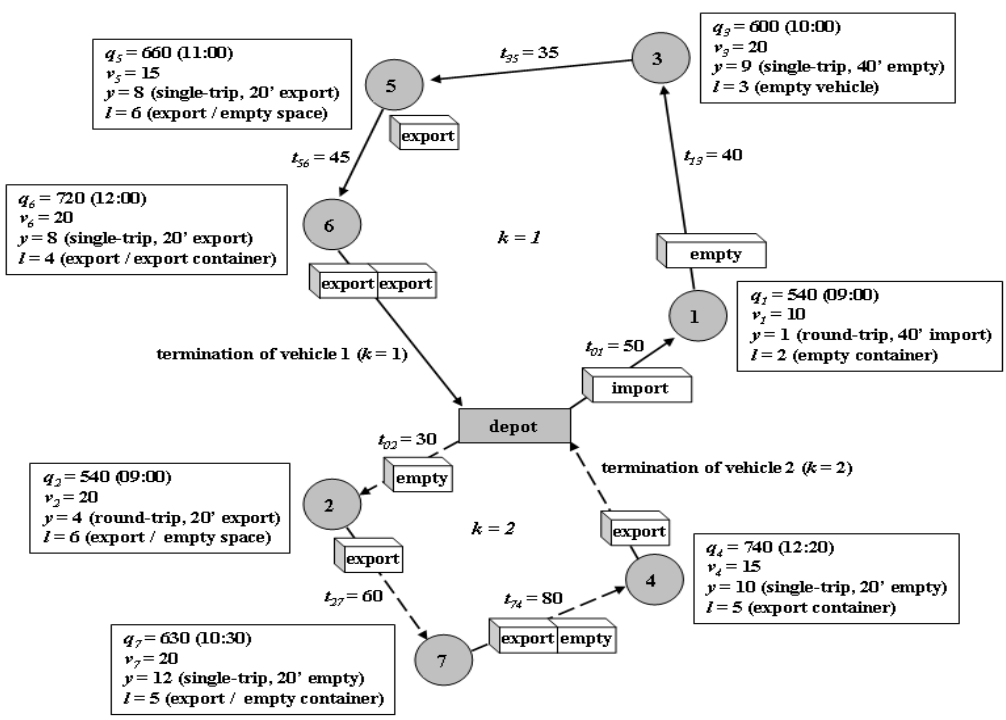


Figure 3. An example of linkage transportation

for completing customer orders.

2.2 Model development

The mathematical model can be formulated as follows:

Objective function:

$$Minimize \sum_{j=1}^{n}\sum_{k=1}^{K}x_{0jk} \tag{1}$$

Subject to

$$\sum_{j=1}^{n}x_{0jk} \le 1, \;\; for\ k \in \{1,\cdots,K\} \tag{2}$$

$$\sum_{j=0}^{n}x_{ijk} = \sum_{j=0}^{n}x_{jik}, \;\; for\ i \in \{0,\cdots,n\}, \; k \in \{1,\cdots,K\}, \; i \ne j \tag{3}$$

$$\sum_{i=0}^{n}\sum_{k=1}^{K}x_{ijk} = 1, \;\; for\ j \in \{1,\cdots,n\}, \; i \ne j \tag{4}$$

$$t_{ij} + M(\sum_{k=1}^{K}x_{ijk} - 1) \le MT, \; for\ i, \; j \in \{1,\cdots,n\}, i \ne j \tag{5}$$

$$q_i + v_i + t_{ij} + M(\sum_{k=1}^{K}x_{ijk} - 1) \le q_j, \; for\ i, \; j \in \{1,\cdots,n\}, \; i \ne j \tag{6}$$

$$q_j - q_i - v_i - t_{ij} + M(\sum_{k=1}^{K}x_{ijk} - 1) \le MH, \; for\ i, \; j \in \{1,\cdots,n\}, \; i \ne j \tag{7}$$

$$\sum_{i=0}^{n}\sum_{j=1, i \ne j}^{n}\sum_{y=2,6}\sum_{l=1}^{6}(R_{ijkyl} \cdot w_j) \le MW, \; for\ k \in \{1,\cdots,K\} \tag{8}$$

$$\sum_{i=0}^{n}\sum_{j=1, i \ne j}^{n}\sum_{y=4,8}\sum_{l=1}^{6}(R_{ijkyl} \cdot w_j) \le MW, \; for\ k \in \{1,\cdots,K\} \tag{9}$$

$$\sum_{i=0}^{n}\sum_{j=1, i \ne j}^{n}\sum_{y=1,5}\sum_{l=1}^{6}R_{ijkyl} \le 1, \;\; for\ k \in \{1,\cdots,K\} \tag{10}$$

$$\sum_{i=0}^{n}\sum_{j=1, i \ne j}^{n}\sum_{y=3,7}\sum_{l=1}^{6}R_{ijkyl} \le 1, \;\; for\ k \in \{1,\cdots,K\} \tag{11}$$

$$\sum_{i=0}^{n}\sum_{j=1, i \ne j}^{n}\sum_{y=2,6}\sum_{l=1}^{6}R_{ijkyl} \le 2, \;\; for\ k \in \{1,\cdots,K\} \tag{12}$$

$$\sum_{i=0}^{n}\sum_{j=1, i \ne j}^{n}\sum_{y=4,8}\sum_{l=1}^{6}R_{ijkyl} \le 2, \;\; for\ k \in \{1,\cdots,K\} \tag{13}$$

$$2 \cdot \sum_{i=0}^{n}\sum_{j=1, i \ne j}^{n}\sum_{y=1,5}\sum_{l=1}^{6}R_{ijkyl} + \sum_{i=0}^{n}\sum_{j=1, i \ne j}^{n}\sum_{y=2,6}\sum_{l=1}^{6}R_{ijkyl} \le 2, \; for\ k \in \{1,\cdots,K\} \tag{14}$$

$$2 \cdot \sum_{i=0}^{n}\sum_{j=1, i \ne j}^{n}\sum_{y=3,7}\sum_{l=1}^{6}R_{ijkyl} + \sum_{i=0}^{n}\sum_{j=1, i \ne j}^{n}\sum_{y=4,8}\sum_{l=1}^{6}R_{ijkyl} \le 2, \; for\ k \in \{1,\cdots,K\} \tag{15}$$

$$\sum_{i=0}^{n}\sum_{y=1}^{12}R_{ijky1} = x_{j0k}, \;\; for\ j \in \{1,\cdots,n\}, \; k \in \{1,\cdots,K\}, \; i \ne j \tag{16}$$

$$\sum_{i=0}^{n}\sum_{j=1, i \ne j}^{n}\sum_{y=1}^{12}R_{ijky2} \le \sum_{j=1}^{n}x_{j0k} + 1, \; for\ k \in \{1, \cdots, K\} \tag{17}$$

$$\sum_{i=0}^{n}\sum_{y=1}^{12}R_{ijky3} + \sum_{i=1}^{n}\sum_{y=1,2,4,5,6,7,8,10,11,12}\sum_{l=1}^{6}R_{jikyl} \le 1, \; for\ j \in \{1,\cdots,n\}, k \in \{1,\cdots,K\}, \; i \ne j \tag{18}$$

$$\sum_{i=0}^{n}\sum_{y=1}^{12}R_{ijky5} + \sum_{i=1}^{n}\sum_{y=1,2,3,4,5,6,9,10}\sum_{l=1}^{6}R_{jikyl} \le 1, \; for\ j \in \{1,\cdots,n\}, k \in \{1,\cdots,K\}, \; i \ne j \tag{19}$$

$$\sum_{i=0}^{n}\sum_{y=1}^{12}R_{ijky2} + \sum_{i=1}^{n}\sum_{y=1,3,5,7,9,11}\sum_{l=1}^{6}R_{jikyl} \le 1, \; for\ j \in \{1,\cdots,n\}, k \in \{1,\cdots,K\}, \; i \ne j \tag{20}$$

$$\sum_{i=0}^{n}\sum_{y=1}^{12}R_{ijky4} + \sum_{i=1}^{n}\sum_{y=1,3,5,7,9,11}\sum_{l=1}^{6}R_{jikyl} \le 1, \; for\ j \in \{1,\cdots,n\}, k \in \{1,\cdots,K\}, \; i \ne j \tag{21}$$

$$\sum_{i=0}^{n}\sum_{y=1}^{12}R_{ijky6} + \sum_{i=1}^{n}\sum_{y=1,3,5,9}\sum_{l=1}^{6}R_{jikyl} \le 1, \; for\ j \in \{1,\cdots,n\}, k \in \{1,\cdots,K\}, \; i \ne j \tag{22}$$

$$\sum_{i=0}^{n}\sum_{y=1}^{12}\sum_{l=2,4}R_{ijkyl} + \sum_{y=1}^{12}\sum_{l=2,4}R_{jckyl} + \sum_{i=1}^{n}\sum_{y=1,2,3,5,6,7,8,9,11,12}\sum_{l=1}^{6}R_{cikyl} \le 2, \; for\ j, c \in \{1,\cdots,n\}, k \in \{1,\cdots,K\}, \; i \ne j \ne c \tag{23}$$

$$\sum_{i=0}^{n}\sum_{y=1}^{12}R_{ijky6} + \sum_{y=1}^{12}R_{jcky6} + \sum_{i=1}^{n}\sum_{y=1,2,3,4,5,6,9,10}\sum_{l=1}^{6}R_{cikyl} \le 2, \; for\ j, c \in \{1,\cdots,n\}, k \in \{1,\cdots,K\}, i \ne j \ne c \tag{24}$$

$$\sum_{y=0}^{12}\sum_{l=1}^{6}R_{ijkyl} = x_{ijk}, \;\; for\ i, j \in \{0,\cdots,n\}, \; k \in \{1,\cdots,K\}, i \ne j \tag{25}$$

$$\forall x_{ijk}, \; \forall R_{ijkyl} \in \{0, 1\} \tag{26}$$

The objective of this model is to minimize the number of vehicles required for transportation. Since all the vehicles start from the depot ($i, j, c = 0$), we can represent the number of vehicles as given by equation (1). Equation (2) to Equation (4) are the same constraints as those in the vehicle routing problem (VRP). Constraint (2) states that each vehicle can only start from the depot. Constraint (3) states that each vehicle transports freight by a continuous route. Constraint (4) states that each customer can transport freight using only one vehicle. Constraints (5) to (7) are equations for the time windows. Constraint (5) defines the transportation time between customers, which must be less than the available transportation time. Constraint (6) defines that the arrival time is less than the customer request time. Constraint (7) states that the waiting time is less than the available waiting time. Constraints (8) and (9) pertain to the container weight. There are no constraints on the weight for a 40-ft container since it cannot take an overload order from a customer. Constraint (8) and Constraint (9) are weight constraints for 20-ft import and export containers on each vehicle, respectively. Constraint (10) to Constraint (15) are allowances for the number of containers transported by one vehicle. Constraints (10) and (11) state that each vehicle can load only one 40-ft import and export container, respectively. Similarly, constraint (12) and Constraint (13) state that each vehicle can load two 40-ft import and export containers, respectively. Constraint (14) and Constraint (15) state that 40-ft import and export containers cannot be loaded along with 20-ft import and export containers, respectively. If a 40-ft export container or two 20-ft export containers are loaded onto a vehicle, the vehicle must return to the depot. Constraint (16) and Constraint (17) give equations for the return of export containers. Constraint (18) to Constraint (22) are equations for linkage transportation. If the vehicle state is a 40-ft empty container ($l = 3$), the vehicle can only link with a 40-ft export container for round-trip transportation ($y = 3$) and the unloading of a 40-ft empty container for single-trip transportation ($y = 9$), as shown in Table 3. This implies that constraints (18) and (19) describe possible order types ($y = 7, 8, 11, 12$) for an empty vehicle. Similarly, constraints (20) to (22) describe order types that can link for each vehicle state. Constraint (23) states that a 20-ft export container for round-trip transportation ($y = 4$) and unloading a 20-ft empty container for single-trip transportation ($y = 10$) can only be linked when the previous two orders have two export or empty containers. Constraint (24) states that the export container for single-trip transportation ($y = 7, 8$) and loading the empty container for single-trip transportation ($y = 11, 12$) can only be linked when the previous two orders have an empty vehicle ($l = 6, 6$). Constraint (25) states that R_{ijkyl} is equivalent to the route of x_{ijk}, and the decision variable is a binary parameter based on constraint (26).

3. Heuristic algorithm

It is very difficult to determine the optimal solution for inland container transportation since it is an NP-hard problem. Therefore, this problem has a property wherein the time required to find the optimal solution rapidly increases with the number of customers. The mathematical model cannot be used to solve large problems. Therefore, we propose a heuristic algorithm that reduces the calculation time required for solving the problem.

In this section, we will describe the heuristic algorithm for linkage transportation and explain its procedure. The 1st customer order that is linked to the depot has one of 12 order types, as shown in <Table 1>, and the 2nd customer order is generated based on the 1st customer order. In other words, the type of the 2nd customer order is one among those listed in <Table 4> and is based on the vehicle state of the 1st customer order. For example, when a vehicle transports a 40-ft import container through round- trip transportation ($y = 1$) for the 1st customer order, the vehicle state is an empty container ($l = 3$). If the 2nd customer order receives the empty container, the vehicle can link a 40-ft export container through round-trip transportation ($y = 3$) and unload a 40-ft empty container through single-trip transportation ($y = 9$), as shown in <Table 4>.

After performing the 1st and 2nd customer orders, the vehicle state is as shown in <Table 4>. If a 20-ft empty container and empty space ($l = 4, 6$) occur after completing previous customer orders, the next customer order can be one among the following: 20-ft export container through round-trip transportation, 20-ft export container through single-trip transportation, unloading a 20-ft empty container through single-trip transportation, and loading a 20-ft empty container through single-trip trans-

Table 4. 1st and 2nd orders that are linked to the depot

1st order			2nd order that is linked to 1st order		
y	vehicle state after order	l	y	vehicle state after order	l
1 11	empty container	3	3	export container	1
			9	empty truck	5
2	empty container	4	2	empty container/empty container	4
			4	export container/empty space	2
			6	empty container/empty space	6
			8	export container/empty container	2
			10	empty space	6
			12	empty container/empty container	4
3 7	export container	1	-	-	-
4 8	export container	2	8	export container/export container	2
			12	export container/empty container	4
5 9	empty truck	5	7	export container	1
			8	export container/empty space	2
			11	empty container	3
			12	empty container/empty space	4
6 10	empty space	6	2	empty container/empty space	4
			4	export container/empty space	2
			5	empty truck	5
			6	empty space/empty space	6
			7	export container	1
			8	export container/empty space	2
			10	empty space/empty space	6
			11	empty container	3
			12	empty container/empty space	4
12	empty container	4	4	export container/empty space	2
			8	export container/empty container	2
			10	empty space	6
			12	empty container/empty container	4

portation (y = 4, 8, 10, 12). Repeated linkage transportation based on the vehicle state is shown in <Table 3>. In the heuristic algorithm described, we will determine the customer order that can link to each vehicle based on this method.

The procedure of the heuristic algorithm for this problem is as follows:

Step 0. 1. Input the constraints allowances-transportation time MT, passage time MP, waiting time MH, and weight MW.
2. Set vehicle k = 0 and transportation sequence e = 0.
3. Sort all customer orders in ascending order based on the request time.

Step 1. 1. The prior customer order selected by request time sequence is $k = k + 1$, $e = e + 1$, $s_0 = q_j - t_{0j}$, $a_j = q_j$ and $s_j = q_j + v_j$.
(s_i : starting time of customer order i, a_j : arrival time of customer order j)

2. Search for an order from the same customer that can link to the previous selected order. The linked customer order must satisfy the constraints with the previous selected customer.
   The constraints are $t_{ij} = 0$, $w_k \le MW$. (w_k : loaded weight in vehicle k)
3. If the searched customer order can be linked with the previous selected customer order, go to Step 2. However, if the linked customer orders have one 40-ft export container and two 20-ft export containers, $a_0 = s_j + t_{j0}$, go to Step 4.
4. Otherwise, go to Step 3.

Step 2.
1. The linked order for the same customer is $e = e + 1$, $a_j = s_i + t_{ij}$ and $s_j = q_j + v_j$.
2. Search for an order from the same customer that can link to the previous customer order. The linked customer order must satisfy the constraints with the previous customer order.
   The constraints are $t_{ij} = 0$, $w_k \le MW$.
3. If the searched customer order can be linked with the previous customer order, go to Step 2. However, if the linked customer orders have one 40-ft export container and two 20-ft export containers, $a_0 = s_j + t_{j0}$, go to Step 4.
4. Otherwise, go to Step 3.

Step 3.
1. Search for a customer order that can link to the previous customer order and satisfy the constraints of the previous customer order.
   The constraints are $t_{ij} \le MT$, $p_{ij} \le MP$, q_j - $a_j \le MH$, $w_k \le MW$.
   (p_{ij} : passage time between customer orders)
2. If the searched customer order can be linked with the previous customer order, the searched customer order is $e = e + 1$, $a_j = s_i + t_{ij}$ and $s_j = q_j + v_j$, go to Step 3.
3. If the linked customer orders have one 40-ft export container and two 20-ft export containers, or there are no more customer orders that can link to the previous customer order,
   $a_0 = s_j + t_{j0}$, go to Step 4.

Step 4.
1. If all customer orders are completed using the vehicle scheduling method, terminate the heuristic algorithm.
2. Otherwise, go to Step 1.

In this procedure, "same customer" implies that the customer name and request time are the same as those of the previous selected customer. The constraints of this procedure are the transportation time, passage time, waiting time, and weight. The transportation time between the customers must be less than the allowed time. Passage time implies the transportation time from a customer to the depot via another customer. The rate of transportation time from a customer to the depot is equal to 100%, and the passage time with another customer is possible until the allowed rate, which is summed to 100%. The waiting time, which is the gap between the customer request time and arrival time, must be less than the allowed time. In addition, the loaded weight in each vehicle must be less than the allowed weight.

The procedure of the heuristic algorithm shows the iteration structure that can be linked by the vehicle states. In this procedure, if a vehicle is loaded with one 40-ft export container or two 20-ft export containers, the vehicle must finish the search for the linkage transportation. If all customer orders are completed by using vehicle scheduling, the heuristic algorithm is terminated.

4. Numerical examples

In this paper, we will use the direct distance based on a comparison with the real distance between two points. <Table 5> shows a comparison of the direct and real distances between the customer and depot. The real distance is obtained by using a navigation device, while the direct distance is obtained using the longitude and latitude.

As shown in <Table 5>, the significance obtained using regression analysis for the 30 direct and real distances had a high level, 99.30%. We performed experiments with the direct distance, which was calculated based on the latitude and longitude between two points.

The mathematical model needed an unacceptable amount of computational time for finding an optimal solution. Therefore, we first compared the mathematical model and heuristic algorithm for small sized (number of customers = 5, 10, 20) problems in order to test their validity. The experimental data for the numerical example were the longitude, latitude, order type, vehicle state, service time, weight, and request time. We performed experiments for the developed mathematical model using LINGO Ver. 10.0 (LINDO Systems Inc.). For the heuristic algorithm, we used the developed scheduling decision support system. The given variable values for each example are $MT = 120$, $MH = 60$, and $MW = 40{,}000$. The example data for five customers are listed in <Table 6>, and the obtained transportation times (minutes) based on the customer longitude and

Table 5. Direct and real distances between the customer and depot

num.	customer		depot		direct distance (Km)	real distance (Km)
	longitude	latitude	longitude	latitude		
1	129.3394	35.5397	128.9639	35.1250	80	80
2	128.6092	35.8722	128.9639	35.1250	125	157
3	128.3450	36.1211	129.0822	35.1088	183	181
4	127.3869	36.3300	128.9639	35.1250	271	281
5	128.7528	35.4625	129.0556	35.1205	66	69
6	128.6994	35.1939	128.9639	35.1250	35	39
7	128.4069	16.1094	128.9639	35.1250	169	175
8	128.7289	35.3064	128.9639	35.1250	41	46
9	128.7444	35.2983	129.0822	35.1088	52	49
10	129.3728	35.5038	128.9639	35.1250	79	89
11	129.2222	35.8939	128.9639	35.1250	125	100
12	129.3056	35.4936	128.9639	35.1250	72	80
13	129.2164	35.8542	128.9639	35.1250	118	92
14	128.6117	35.8528	129.0822	35.1088	130	148
15	128.3772	35.1217	129.0822	35.1088	88	94
16	126.8767	35.1128	128.9639	35.1250	258	251
17	127.6733	34.7653	128.9639	35.1250	170	196
18	129.0800	35.2350	129.0556	35.1205	19	27
19	127.4825	34.9544	128.9639	35.1250	186	181
20	128.8731	35.2272	128.9639	35.1250	20	24
21	128.8328	35.1667	129.0556	35.1205	29	29
22	128.5733	35.2117	128.9639	35.1250	51	59
23	128.6119	35.2478	129.0556	35.1205	59	57
24	127.3695	36.3001	129.0822	35.1088	282	292
25	127.8477	36.2328	128.9639	35.1250	221	231
26	127.5857	35.9149	128.9639	35.1250	211	224
27	127.0563	36.7656	128.9639	35.1250	348	358
28	127.7033	36.0107	128.9639	35.1250	209	239
29	127.1869	36.6806	128.9639	35.1250	327	337
30	127.4300	36.9624	128.9639	35.1250	343	361

Table 6. Data for five customers

customer	longitude	latitude	order type(y)	vehicle state(l)	service time(v)	weight(w)	request time(q)
0	128.9639	35.1250					
1	128.6994	35.1939	6	6	30	15,000	350
2	128.7528	35.4625	4	2	50	20,000	420
3	129.3394	35.5397	1	3	30	39,000	540
4	128.3450	36.1211	8	2	20	18,000	570
5	128.6092	35.8722	3	1	20	36,000	670

latitude are shown in <Table 7>.

Table 7. Transportation times for five customers

customer	0	1	2	3	4	5
0	0	30	51	69	149	107
1	30	0	37	83	130	92
2	51	37	0	64	99	57
3	69	83	64	0	131	90
4	149	130	99	131	0	44
5	107	92	57	90	44	0

The experimental results for the mathematical model and the heuristic algorithm are shown in <Table 8> and <Table 9>. There were two scheduled vehicles and their transportation routes were the same.

Table 8. Results of the mathematical model for five customers

vehicle(k)	vehicle route
1	0 → 1 → 2 → 4 → 0
2	0 → 3 → 5 → 0

The results for 10 and 20 customers are shown in <Table 10>, <Table 11>, <Table 12>, and <Table 13>. In the case of 10 customers, there were five scheduled vehicles and their transportation routes were the same.

Table 10. Results of the mathematical model for ten customers

vehicle(k)	vehicle route
1	0 → 1 → 3 → 5 → 0
2	0 → 2 → 0
3	0 → 4 → 6 → 0
4	0 → 7 → 9 → 0
5	0 → 8 → 10 → 0

In the case of 20 customers, both the mathematical program and heuristic algorithm also produced the same objective value which was 9. Even though the transportation routes were the same for both solutions, the allocated vehicles to the routes were different.

Table 9. Results of the heuristic algorithm for five customers

customer	vehicle(k)	sequence(s)	move time	depot starting	arrival time	starting time	depot arrival
1	1	1	31	5 : 19	5 : 50	6 : 20	
2	1	2	43		6 : 57	7 : 50	
3	2	1	81	7 : 51	9 : 00	9 : 30	
4	1	3	116		9 : 29	9 : 50	12 : 19
5	2	2	104		10 : 59	11 : 30	13 : 17

Table 11. Results of the heuristic algorithm for ten customers

customer	vehicle(k)	sequence(s)	move time	depot starting	arrival time	starting time	depot arrival
1	1	1	31	5 : 19	5 : 50	6 : 20	
2	2	1	32	5 : 28	6 : 00	6 : 20	6 : 52
3	1	2	37		6 : 57	7 : 50	
4	3	1	69	7 : 51	9 : 00	9 : 30	
5	1	3	99		9 : 29	9 : 50	12 : 19
6	3	2	89		10 : 59	11 : 30	13 : 17
7	4	1	231	7 : 39	11 : 30	11 : 40	
8	5	1	36	13 : 24	14 : 00	15 : 00	
9	4	2	112		13 : 32	14 : 50	17 : 15
10	5	2	3		15 : 03	16 : 30	17 : 03

Table 12. Results of the mathematical model for twenty customers

vehicle(k)	vehicle route
1	0 → 16 → 0
2	0 → 8 → 9 → 10 → 13 → 0
3	0 → 18 → 20 → 0
4	0 → 14 → 17 → 19 → 0
5	0 → 1 → 3 → 5 → 0
6	0 → 4 → 6 → 0
7	0 → 11 → 15 → 0
8	0 → 2 → 0
9	0 → 7 → 12 → 0

For the experimental investigation, we randomly generated five examples for 50 and 100 customer orders in order to simulate a number of customer orders using the heuristic algorithm. The randomly created data included the customer order type, request time, service time, weight, longitude, and latitude. The given constraint values for this examples were as follows:

- allowance weight of each vehicle = 40,000kg, average vehicle speed = 70km/h,
- available waiting time = 60min, available transportation time = 180min,
- allowance rate of passage time = 120%

<Table 14> and <Table 15> show the results of the experiments with five examples for both 50 and 100 customer orders. In <Table 14>, the first example was scheduled with 32 vehicles. This implied that one vehicle could transport five customer orders, and two vehicles could transport four customer orders each. From the results of this experiment, we observed that more than half of the customer orders were scheduled for linkage transportation. The computational time was less than 1 second in these experiments, therefore we determined that the heuristic algorithm performed well.

Table 13. Results of the heuristic algorithm for twenty customers

customer	vehicle(k)	sequence(s)	move time	depot starting	arrival time	starting time	depot arrival
1	1	1	31	5 : 19	5 : 50	6 : 20	
2	2	1	32	5 : 28	6 : 00	6 : 20	6 : 52
3	1	2	37		6 : 57	7 : 50	
4	3	1	69	7 : 51	9 : 00	9 : 30	
5	1	3	99		9 : 29	9 : 50	12 : 19
6	3	2	89		10 : 59	11 : 30	13 : 17
7	4	1	231	7 : 39	11 : 30	11 : 40	
8	5	1	221	7 : 49	11 : 30	11 : 40	
9	5	2	22		12 : 02	12 : 30	
10	5	3	75		13 : 45	14 : 00	
11	6	1	36	13 : 24	14 : 00	15 : 00	
12	4	2	112		13 : 32	14 : 50	17 : 15
13	5	4	30		14 : 30	15 : 40	18 : 06
14	7	1	222	11 : 48	15 : 30	15 : 40	
15	6	2	3		15 : 03	16 : 30	17 : 04
16	8	1	67	14 : 33	15 : 40	16 : 10	17 : 17
17	7	2	6		15 : 46	16 : 20	
18	9	1	106	14 : 54	16 : 40	16 : 50	
19	7	3	16		16 : 36	17 : 50	21 : 13
20	9	2	55		17 : 45	18 : 10	19 : 12

Table 14. Results of five examples for 50 customers

Problem instance	vehicle counting for the number of linked customers						total vehicle number
	1	2	3	4	5	6	
1	22	6	1	2	1		32
2	17	7	4			1	29
3	17	11			1	1	30
4	16	11	3	1			31
5	23	8	2	1			34

Table 15. Results of five examples for 100 customers

Problem instance	vehicle counting for the number of linked customers						total vehicle number
	1	2	3	4	5	6	
1	31	16	4	1	3	1	56
2	26	18	6		4		54
3	31	11	6	6	1		55
4	21	22	7	1	2		53
5	22	19	8	4			53

5. Decision support system

We developed a decision support system that could schedule vehicles by means of a heuristic algorithm. It has been developed using Delphi 6.0 (Borland International, Inc.) and SQL Server 2000 (Microsoft Corporation). This system (shown in <Figure 4>) not only determined the optimal vehicle scheduling for the customer orders but also provided the total transportation distance and time. This system accepted constraint elements that were required to find the optimal vehicle routes for the customer orders.

The constraint elements were the maximum weight and allowance rate of each vehicle, average vehicle speed, waiting time, transportation time, and passage time that was allowed. If we run the decision support system after inputting the constraint elements that are required to find the optimal transportation routes, vehicle scheduling is performed by using the developed heuristic algorithm. The transportation times between the customers were calculated automatically based on the longitude and latitude of the customers. We could see the starting/arrival times for each customer and vehicle in the depot. In addition, this system provided total transportation distance and time of all vehicles.

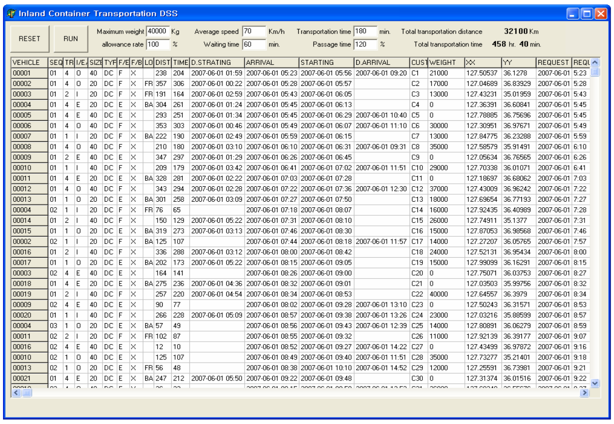


Figure 4. Screen of optimal vehicle scheduling

6. Conclusions

The problems of container transportation are very complex due to several factors, such as transportation type, container size and type, and freight weight. In this paper, we considered two types of transportation, namely, round-trip and single-trip transportation, and described 12 customer order types and 6 vehicle states based on the customer order information. We introduced a mathematical model and a heuristic algorithm to perform vehicle scheduling for inland container transportation. From the numerical experiments, we confirmed that our algorithms were able to find the optimal or near-optimal solutions that minimize the required number of vehicles by scheduling routes through linkage transportation. We also developed a decision support system based on this algorithm. Further research focusing on inserting another route for the vehicles during the idle time of each vehicle that has a schedule would be beneficial since this would reduce the total number of vehicles required. Furthermore, it will be necessary to conduct an overall study of inland transportation that is linked with local and shuttle transportation.

References

Crainic, T. G., Grendreau, M. and Dejax, P. J. (1993), Dynamic and stochastic models for the allocation of empty containers, *Operations Research*, 41(1), 102-126.

Cullen, F. H., Jarvis, J. J. and Ratliff, H. D. (1981), Set partitioning based heuristics for interactive routing, *Networks*, 11, 125-143.

Dumas, Y., Desrosiers, J. and Soumis, F. (1991), The pickup and delivery problem with time windows, *European Journal of Operational*

Research, 54, 7-22.

Kim, D. H., Lee, C. H. and Kim, B. S. (1997), Truck dispatching decision support system for the container transportation problem, *Journal of the Korea Institute of Industrial Engineers*, 23(2), 275-288.

Ko, C. S., Chung, G. H. and Shin, J. Y. (2000), Determination of vehicle fleet size for container shuttle service, *Journal of the Korean Operations and Management Science Society*, 17(2), 87-95.

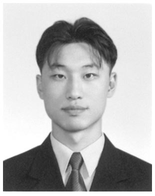
Ko, C. S., Chung, G. H., Shin, J. Y., Kim, H. B., Yang, C. S. and Park, S. C. (2002), Determination of vehicle fleet size for container transportation service in a stochastic work environment, *Journal of the Korean Production and Operations Management Society*, 12(3), 17-32.

Koo, P. H., Jang, D. W. and Lee, W. S. (2003), Fleet sizing and vehicle routing for static freight container transportation, *IE Interfaces*, 16(2), 174-184.

Korea International Trade Association (2007), Domestic transportation report about import/export container freight in 2006.

Samsung Economic Research Institute (2003), The present condition and the assignment for logistics industry.

Yun, W. Y., Ahn, C. G. and Choi, Y. S. (1999), A truck dispatching problem in the inland container transportation with empty container, *Journal of the Korean Operations and Management Science Society*, 24(4), 63-80.



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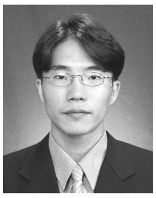

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