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# 전시 최장 획득완료시간 최소화를 위한 복수 순회구매자 문제

## The Multiple Traveling Purchaser Problem for Minimizing the Maximal Acquisition Completion Time in Wartime

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Abstract

In war time, minimizing the logistics response time for supporting military operations is strongly needed. In this paper, i propose the mathematical formulation for minimizing the maximal acquisition completion time in wartime or during a state of emergency. The main structure of this formulation is based on the traveling purchaser problem (TPP), which is a generalized form of the well-known traveling salesman problem (TSP). In the case of the general TPP, an objective function is to minimize the sum of the traveling cost and the purchase cost. However, in this study, the objective function is to minimize the traveling cost only. That's why it's more important to minimize the traveling cost (time or distance) than the purchase cost in wartime or in a state of emergency. I generate a specific instance and find out the optimal solution of this instance by using ILOG OPL STUDIO (CPLEX version 11.1).

Keywords : Military Logistics, Traveling Purchase Problem, Supply Chain Management

## 1. Introduction

Military logistics is the art and science of planning and carrying out the movement and maintenance of military forces. In its most comprehensive sense, it is those aspects or military operations that deal with the acquisition, storage, and distribution of military materials.

The military activity known as logistics probably is as old as war itself. In the early history of man when the first wars were fought, each man had to find his own food, stones, and knotted clubs. Each warrior was responsible for foraging for his own food and firewood. Not until later, when fighters joined as groups and fighting groups became larger, was there any basis for designating certain men to specialize in providing food and weapons to the combatants. The men who provided support to the fighters constituted the first logistics organization.

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The concept of modern military logistics is as follows. Logistics, occasionally referred to as “combat service support”, must address highly uncertain conditions. While perfect forecasts are rarely possible, forecast models can reduce uncertainty about what supplies or services will be needed, where and when they will be needed, or the best way to provide them. Ultimately, responsible officials must make judgements on these matters, sometimes using intuition and scientifically weighing alternatives as the situation requires and permits. Their judgements must be based not only upon professional knowledge of the numerous aspects of logistics itself but also upon an understanding of the interplay of closely related military considerations such as strategy, tactics, intelligence, and finance.

The Republic of Korea enact the requisition law for supporting military operations in wartime or in a state of emergency. In wartime, the most important factor of logistics operation is to minimize the acquisition completion time. In this paper, i suggest the multiple traveling purchaser problem for minimizing the maximal acquisition completion time for the commandeered materials based on the MTPP (multiple traveling purchaser problem). It could be used in the inbound logistics optimization area, commercially, with Just-in-Time (JIT) operations and for military logistics operations.

Ramesh[13] suggested the traveling purchaser problem (TPP). TPP as a generalized type of well-known TSP (traveling salesman problem) is defined as follows. Let us consider a set of products to be purchased with the purchaser located originally at a depot. There is a requirement of units for each different product. Let us also consider a set of markets, each selling some units of a certain number of products. The unit price of a product depends on the market where it is available. The travel cost between any two markets is also known. The TPP asks for the selection of a subset of markets and routes to the selected markets with a vehicle such that the demand for each product is satisfied and the total purchasing and travel cost is minimized. It is assumed that each product is available in at least one market, no product is available in the depot and the required demand must be purchased.

All the past research of the TPP are restricted by only having one purchaser. In this paper, i suggest a multiple traveling purchaser problem for minimizing the maximal acquisition completion time for the commandeered materials.

## 2. Literature review

Ramesh[13] proposed the TPP for the first time and developed two algorithms for solving the TPP. The first one is the lexicographic search which is an exact algorithm to find out the optimal solution. The second is a heuristic method which is called the near neighbor algorithm which starts by inserting a market into a tour and then extending the tour by inserting other markets into the tour repeatedly in greedy way.

Golden et al.[5] proposed the GSH (generalized savings heuristic) for solving the TPP. It starts with an initial solution which includes the depot and the market selling more products than any other market at the cheapest price. The GSH selects a market based on the savings calculated from the travel and purchase costs and inserts that market into the current tour repeatedly and terminates when no more savings can be made.

Ong[11] proposed the TRH (tour reduction heuristic) which is an improved version of the GSH.

Voß[19] presented the meta-heuristic approaches for the TPP based on a dynamic tabu search and simulated annealing.

Singh and Oudheusden[17] developed a branch-and-bound algorithm for the TPP. The basic idea of it is that the selection of a subset of markets for the tour and the determination of the optimal tour of these markets are successfully embedded into one methodology.

Pearn and Chien[12] improved on the two previous works of Golden et al.[5] and Ong[11]. They suggested three heuristic methods: the PS-GSH (parameter selection GSH), the TS-GSH (tie selection GSH), and the CAH (commodity adding heuristic).

Laporte et al.[7] developed the MAH (market adding heuristic) for the TPP.

Boctor et al.[2] proposed three PH (perturbation heuristics) based on a tabu search: UPH1, UPH2, and CPH. These three heuristics consist of seven basic procedures: market drop, market add, market exchange, the TSP heuristic, cheapest insertion, double market drop, and double market exchange.

Teeninga and Volgenant[18] introduced pre-processing and intensification procedures for three previous algorithms, which were the like GSH, the CAH, and the TRH.

Riera-Ledesma and Salazar-Gonalez[14] proposed the LS (local search) algorithm. Riera-Ledesma and Salazar-Gonalez[15] also suggested the 2-TPP (bi-objective TPP). The objective of the 2-TPP is to minimize the travel cost and purchase cost simultaneously.

Riera-Ledesma and Salazar-Gonalez[16] introduced an exact algorithm for the TPP. They find out the optimal solution for the TPP by using a branch-and-cut algorithm.

In recent year, Bontoux and Feillet[3] proposed the DMD-ATA (dynamic multi-dimensional anamorphic traveling ants algorithm) based on ACO (ant colony optimization) and the LS algorithm. Goldbarg et al.[4] proposed the TA (transgenetic algotithm) based on horizontal gene transfer[6] and endosymbiosis[9]. Angelelli et al.[1] introduced the D-TPP (dynamic TPP) in which the quantity of products at markets is decreased due to the flow of time. Mansini and Tocchella[8] proposed the TPP-B (TPP with budget constraint) in which the travel cost is minimized in an objective function and the purchase cost is restricted within the constraint.

The number of purchasers in all the TPP studies is limited to a single-purchaser. I suggest the MTPP for minimizing the maximal acquisition completion time. It assumed that the number of depots is 1 and that each purchaser (vehicle) has same purchase (loading) capacity.

## 3. Mathematical Formulation

### 3.1 Brief and assumption

As a generalization of the single TPP, in the MTPP to be reviewed in this section, several vehicles of a given capacity originally start and end the route at a supply depot and minimize the total travel cost and purchase cost with satisfaction of the demand. However, the purpose of this paper is to minimize the maximal acquisition (purchase) completion time. Therefore i only consider the travel cost (time) except for the purchase cost.

In order to build a mathematical formulation of this problem, the following are assumed.

- Several vehicles with the same given capacity are originally at a supply depot.
- Each vehicle starts and ends the route at the supply depot.
- A vehicle visiting the market (defense contractor) is allowed only to visit each market once and the purchased products (military materials) from the defense contractors in the vehicle path will be transported by the vehicle to the supply depot.
- Each military material is available from at least one defense contractor and no military material is available from the supply depot.
- The required demand must be purchased.
- If the demand for the military materials are satisfied it is not mandatory to visit every defense contractor.

### 3.2 The formulation for minimizing the total acquisition (purchase) completion time

In this section i introduce the mathematical formulation for minimizing the total purchase completion time.

<Notation>

$m$ : the number of defense contractors indexed by $i$, $i \in M = \{1, \cdots, m\}$, $i = 1$ : supply depot

$n$ : the number of military materials indexed by $l$, $l \in N = \{1, \cdots, n\}$

$v$ : the number of vehicles indexed by $k$, $k \in V = \{1, \cdots, v\}$

$c_{ij}$ : the travel time between defense contractor $i$ and $j$, $j \in M$ , $j = 1$ : depot

$d_l$ : the demand for military material $l$

$q_{il}$ : the quantity of military material $l$ available at defense contractor $i$

$C$ : the capacity of the vehicle

<Decision variable>

$$x_{ijk} = \begin{cases} 1 & \text{if vehicle } k \text{ visit defense contractor } j \text{ immediately after } i \\ 0 & \text{otherwise} \end{cases}$$

$y_{ikl}$ : Quantity of military material $l$ purchased by vehicle $k$ at military contractor $i$

$$\textit{Minimize} \sum_{i \in M}\sum_{j \in M}\left(c_{ij}\sum_{k \in V}x_{ijk}\right) \quad (1)$$

*Subject to*

$$\sum_{i \in M}\sum_{k \in V}x_{ijk} \le 1 \qquad \forall j \in M \setminus \{1\} \quad (2)$$

$$\sum_{i \in M}x_{ihk} - \sum_{j \in M}x_{hjk} = 0 \qquad \forall h \in M, \forall k \in V \quad (3)$$

$$\sum_{j \in M \setminus \{1\}}x_{1jk} = 1 \qquad \forall k \in V \quad (4)$$

$$u_i - u_j + m\sum_{k \in V}x_{ijk} \le m-1 \quad \forall i \in M, \forall j \in M, 2 \le i \ne j \le m, \quad u_i, u_j : \text{arbitrary} \quad (5)$$

$$\sum_{i \in M \setminus \{1\}}\sum_{k \in V}y_{ikl} = d_l \qquad \forall l \in N \quad (6)$$

$$q_{il}\sum_{j \in M}x_{ijk} - y_{ikl} \ge 0 \qquad \forall i \in M \setminus \{1\},\ \forall k \in V, \forall l \in N \quad (7)$$

$$q_{il}\sum_{j \in M}x_{jik} - y_{ikl} \ge 0 \qquad \forall i \in M \setminus \{1\},\ \forall k \in V, \forall l \in N \quad (8)$$

$$\sum_{i \in M \setminus \{1\}}\sum_{l \in N}y_{ikl} \le C \qquad \forall k \in V \quad (9)$$

$$x_{ijk} \in \{0,1\} \qquad \forall i \in M, \forall j \in M, \forall k \in V \quad (10)$$

$$y_{ikl} \ge 0 \qquad \forall i \in M \setminus \{1\}, \forall k \in V, \forall l \in N \quad (11)$$

Objective function (1) means minimizing the total acquisition (purchase) completion time in the optimal tour. Constraint (2) means the vehicle visiting the defense contractor is allowed to visit once, and if the demand for the military materials is satisfied by some selected defense contractors then visiting the remaining defense contractors is not needed. Constraint (3) represents the continuity of the vehicle route. Constraint (4) means that all vehicles at the depot can start only once. Constraint (5) represents the SECs (subtour elimination constraints) which is a constraint proposed by Miller et al.[10]. It's an extended version of Miller et al.'s SECs in the TSP and could be applied in the mCSTPP. Constraint (6) means all demands should be purchased in an amount as exactly required. Constraints (7), and (8) means that a defense contractor should be included in the tour prior to the purchase of military material from that defense contractor. They also represent that the purchaser can purchase military material from the defense contractor if the military material exists at that defense contractor, and these constraints also mean that the quantity of the purchased military material at the defense contractor should be less than the quantity available at that defense contractor. Constraint (9) represents the given capacity of the vehicle. Constraint (10), (11) represent the variables' integer conditions.

### 3.3 Formulation for minimizing maximal acquisition (purchase) completion time

In this section i introduce the mathematical formulation for minimizing the maximal acquisition (purchase) completion time. In this case, the decision variables $x_{ijk}$, $y_{ikl}$ have the same meaning as in section 3.2. However, decision variable $z$ is newly added and has the following meaning.

$z$ : The Total travel time of the vehicle which returns last to a depot

With the same notation as that in section 3.2, the mathematical formulation for minimizing the maximal acquisition (purchase) completion time is as follows.

$$\textit{Minimize } z \quad (12)$$

*Subject to*

$$z \ge \sum_{i \in M}\sum_{j \in M}\left(c_{ij}\sum_{k \in V}x_{ijk}\right) \quad (13)$$

$$\sum_{i \in M} \sum_{k \in V} x_{ijk} \le 1 \qquad \forall j \in M \setminus \{1\} \qquad (14)$$

$$\sum_{i \in M} x_{ihk} - \sum_{j \in M} x_{hjk} = 0 \qquad \forall h \in M, \forall k \in V \qquad (15)$$

$$\sum_{j \in M \setminus \{1\}} x_{1jk} = 1 \qquad \forall k \in V \qquad (16)$$

$$u_i - u_j + m \sum_{k \in V} x_{ijk} \le m - 1 \quad \forall i \in M, \forall j \in M, 2 \le i \ne j \le m$$
$$u_i, u_j \text{ : arbitrary} \qquad (17)$$

$$\sum_{i \in M \setminus \{1\}} \sum_{k \in V} y_{ikl} = d_l \qquad \forall l \in N \qquad (18)$$

$$q_{il} \sum_{j \in M} x_{ijk} - y_{ikl} \ge 0 \qquad \forall i \in M \setminus \{1\}, \forall k \in V, \forall l \in N \qquad (19)$$

$$q_{il} \sum_{j \in M} x_{jik} - y_{ikl} \ge 0 \qquad \forall i \in M \setminus \{1\}, \forall k \in V, \forall l \in N \qquad (20)$$

$$\sum_{i \in M \setminus \{1\}} \sum_{l \in N} y_{ikl} \le C \qquad \forall k \in V \qquad (21)$$

$$x_{ijk} \in \{0, 1\} \qquad \forall i \in M, \forall j \in M, \forall k \in V \qquad (22)$$

$$y_{ikl} \ge 0 \qquad \forall i \in M \setminus \{1\}, \forall k \in V, \forall l \in N \qquad (23)$$

The objective function (12) and constraint (13) let the maximal acquisition (purchase) be completed in the least time. Constraints (14) ~ (23) have the same meanings as formulas (2) ~ (11).

## 4. Experiment

### 4.1 Experiment conditions

The conditions of the experiment are as follows. First, i randomly generated the coordinates of the defense contractors including the depot according to a uniform distribution in a 100×100 2-dimensional plane. I set the number of military materials $n$ equal to the number of defense contractors $m(m=n)$. In the experiment, i find out the optimal solution by using ILOG CPLEX (version 11.1). The experiments are conducted with a PC Pentium4 2 GHz.

### 4.2 Generation of instance and solution

#### 4.2.1 Instance

I generated 15 defense contractors including the depot and same number of military materials. Table 1

Table 1. Travel time between defense contractors

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 51 | 26 | 37 | 20 | 20 | 52 | 14 | 30 | 37 | 29 | 33 | 33 | 59 | 42 |
| 2 | 51 | 0 | 40 | 64 | 35 | 71 | 17 | 58 | 77 | 69 | 23 | 27 | 84 | 109 | 55 |
| 3 | 26 | 40 | 0 | 24 | 31 | 40 | 33 | 22 | 56 | 61 | 28 | 13 | 49 | 72 | 20 |
| 4 | 37 | 64 | 24 | 0 | 51 | 39 | 54 | 24 | 61 | 74 | 51 | 36 | 40 | 58 | 14 |
| 5 | 20 | 35 | 31 | 51 | 0 | 39 | 42 | 32 | 41 | 35 | 13 | 29 | 54 | 79 | 51 |
| 6 | 20 | 71 | 40 | 39 | 39 | 0 | 71 | 18 | 23 | 41 | 49 | 50 | 14 | 40 | 49 |
| 7 | 52 | 17 | 33 | 54 | 42 | 71 | 0 | 55 | 82 | 78 | 30 | 21 | 82 | 106 | 43 |
| 8 | 14 | 58 | 22 | 24 | 32 | 18 | 55 | 0 | 38 | 50 | 38 | 34 | 27 | 51 | 32 |
| 9 | 30 | 77 | 56 | 61 | 41 | 23 | 82 | 38 | 0 | 22 | 54 | 63 | 32 | 51 | 70 |
| 10 | 37 | 69 | 61 | 74 | 35 | 41 | 78 | 50 | 22 | 0 | 48 | 63 | 54 | 74 | 79 |
| 11 | 29 | 23 | 28 | 51 | 13 | 49 | 30 | 38 | 54 | 48 | 0 | 20 | 62 | 88 | 47 |
| 12 | 33 | 27 | 13 | 36 | 29 | 50 | 21 | 34 | 63 | 63 | 20 | 0 | 61 | 85 | 29 |
| 13 | 33 | 84 | 49 | 40 | 54 | 14 | 82 | 27 | 32 | 54 | 62 | 61 | 0 | 25 | 54 |
| 14 | 59 | 109 | 72 | 58 | 79 | 40 | 106 | 51 | 51 | 74 | 88 | 85 | 25 | 0 | 72 |
| 15 | 42 | 55 | 20 | 14 | 51 | 49 | 43 | 32 | 70 | 79 | 47 | 29 | 54 | 72 | 0 |

represents the travel time between defense contractors. In Table 1, defense contractor 1 is the supply depot.

Table 2 represents the demand for the 15 military materials.

Table 3 represents the inventories of 15 defense contractors. The inventory of the military materials of defense contractor 1 is zero because defense contractor 1 is the supply depot.

I set the capacity of each vehicle to 5,000. Therefore, 3 vehicles need to operate because the demand is 14,500, as shown in Table 2.

Table 2. Demand for 15 military materials

| Material | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Demand | 700 | 1,600 | 700 | 500 | 800 | 1,400 | 1,800 | 700 | 500 | 1,900 | 600 | 1,500 | 800 | 400 | 600 | 14,500 |

Table 3. Inventory of defense contractors

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2 | 0 | 600 | 900 | 900 | 500 | 0 | 900 | 700 | 700 | 600 | 800 | 900 | 600 | 500 | 500 |
| 3 | 800 | 600 | 500 | 500 | 0 | 800 | 800 | 500 | 900 | 900 | 0 | 600 | 800 | 700 | 0 |
| 4 | 700 | 0 | 0 | 0 | 900 | 900 | 0 | 900 | 700 | 600 | 700 | 500 | 500 | 700 | 0 |
| 5 | 0 | 700 | 800 | 0 | 0 | 800 | 0 | 900 | 600 | 500 | 700 | 600 | 700 | 700 | 700 |
| 6 | 900 | 0 | 0 | 600 | 0 | 0 | 700 | 0 | 0 | 600 | 700 | 0 | 0 | 0 | 800 |
| 7 | 700 | 800 | 0 | 600 | 600 | 0 | 0 | 0 | 600 | 800 | 0 | 500 | 900 | 500 | 800 |
| 8 | 800 | 900 | 800 | 500 | 600 | 600 | 0 | 600 | 0 | 700 | 0 | 0 | 0 | 0 | 900 |
| 9 | 0 | 0 | 0 | 500 | 800 | 600 | 500 | 0 | 500 | 0 | 700 | 900 | 0 | 0 | 900 |
| 10 | 0 | 800 | 600 | 0 | 700 | 900 | 700 | 600 | 800 | 700 | 800 | 0 | 800 | 0 | 0 |
| 11 | 700 | 900 | 900 | 0 | 0 | 0 | 0 | 500 | 0 | 900 | 900 | 600 | 600 | 700 | 600 |
| 12 | 800 | 0 | 0 | 0 | 900 | 0 | 0 | 500 | 0 | 900 | 500 | 0 | 0 | 500 | 0 |
| 13 | 600 | 500 | 800 | 900 | 800 | 700 | 600 | 500 | 600 | 0 | 0 | 800 | 500 | 800 | 0 |
| 14 | 0 | 600 | 0 | 0 | 700 | 500 | 700 | 0 | 700 | 500 | 0 | 700 | 700 | 700 | 700 |
| 15 | 0 | 800 | 600 | 600 | 700 | 500 | 800 | 800 | 900 | 600 | 600 | 900 | 0 | 0 | 900 |

Table 4. Experiment result

| Case | Vehicle ID | Route | Number of visiting defense contractors | Purchase quantity | Travel Time | Total travel time | Computing Time(SEC) |
|---|---|---|---|---|---|---|---|
| 1 | 1 | 1-5-1 | 1 | 5,000 | 40 | 159 | 18.04 |
| | 2 | 1-3-1 | 1 | 4,500 | 52 | | |
| | 3 | 1-13-6-1 | 2 | 5,000 | 67 | | |
| 2 | 1 | 1-3-1 | 1 | 5,000 | 52 | 185 | 33.5 |
| | 2 | 1-6-13-1 | 2 | 5,000 | 67 | | |
| | 3 | 1-8-5-1 | 2 | 4,500 | 66 | | |

### 4.2.2 Optimal solution

I assume Case 1 and Case 2 as follows.

- Case 1 : Minimizing the total acquisition (purchase) completion time model

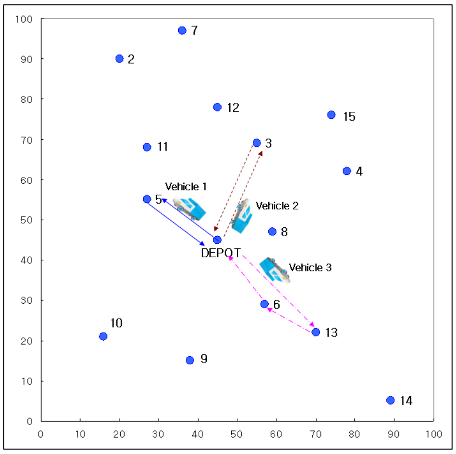
- Case 2 : Minimizing the maximal acquisition (purchase) completion time model

The experiment result for both Cases for the given instance described in 4.2.1 is shown in Table 4. The total travel time is 159 in Case 1 and 185 in Case 2. The minimum maximal purchase completion time is calculated as 67 in both cases.

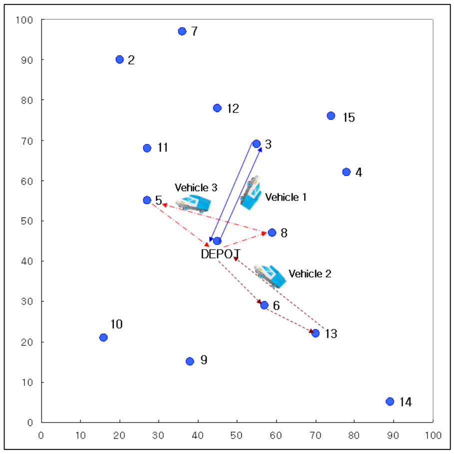
Fig. 1 represents the optimal tour of each vehicle in both Cases.

### 4.3 Computational complexity

Both problems in section 3.2 and 3.3 are NP-hard. Therefore, consideration of the computing time change due to an increase of the problem size is needed. I set $m$ and $n$ that are equally increased from 10 to 30 in increments of 5 units. I randomly generated the required quantities of demand, $d_l$ in [1, 20]×100, and the number of available military material $l$ at defense contractor $i$, $q_{il}$ in [0, 10]×100. I also set the capacity of each vehicle as 5,000 and applied a lower bound to the number of vehicles for the satisfaction of the total demand in each instance.




(a) Case 1




(b) Case 2

Fig. 1. Optimal tour of each vehicle

Table 5. Computational time of both cases

| Size | | | | Case 1 | | | | Case 2 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| m | n | Total demand | LBV | NMC | Computing time | | | NMC | Computing time | | |
| | | | | | hour | minute | second | | hour | minute | second |
| 10 | 10 | 9,800 | 2 | 4 | - | - | 1.26 | 4 | - | - | 2.01 |
| 15 | 15 | 14,500 | 3 | 4 | - | - | 18.04 | 5 | - | - | 33.5 |
| 20 | 20 | 19,500 | 4 | 6 | - | 6 | 13.54 | 5 | - | 8 | 49.28 |
| 25 | 25 | 23,600 | 5 | 6 | - | 23 | 34.59 | - | - | - | - |
| 30 | 30 | 28,900 | 6 | 7 | 1 | 38 | 25.7 | - | - | - | - |

Note) LBV: Lower bound of the number of needed vehicles for the satisfaction of the total demand
NMC: Number of defense contractors in the optimal tour

The results are shown in Table 5. In case 1, optimal solutions are calculated within reasonable times in the case where $m$ (or $n$) is under 25. However, for $m$ (or $n$) equal to 30, it takes more than 1 hour for the calculation of the optimal value. In case 2, the optimal solution is calculated within a reasonable time in the case where $m$ (or $n$) is under 20. But, for $m$ (or $n$) values over 25, optimal solutions couldn't be found due to the limitation of the memory capacity of CPLEX. Therefore, i could say that the computational complexity of case 2 is higher than case 1.

Fig. 2 shows the computing time change due to increase of the problem size in case 1 and case 2.

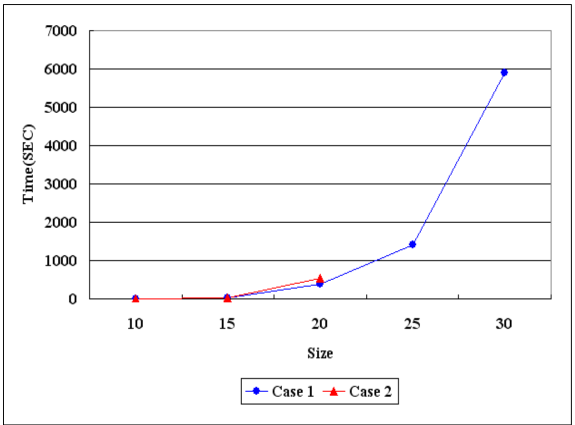



Fig. 2. Computing time change for problem size

In both cases, i can see computing time exponentially increases depending on the increase in the problem size. In particular, longer computing time is needed in case 2.

## 5. Conclusions and future works

In this paper, i introduced two mathematical formulations of minimizing the total acquisition (purchase) completion time model and minimizing the maximal acquisition (purchase) completion time. They could be used for JIT operations commercially and for military logistics operation in wartime.

I calculated the optimal solution in each case for 10, 15, 20, 25 and 30 defense contractors and military materials by using the commercial optimization tool ILOG CPLEX. However, in case 2, when the number of defense contractors (or military materials) is over 25, i could not find optimal solutions due to the limitation of the memory capacity of CPLEX. Therefore development of a heuristic method for solving this problem is needed. In particular, a meta-heuristic such as GA (genetic algorithms), PSO (particle swarm optimization) and NN (neural networks) which are not yet applied to the TPP are needed for application to problems in this area.

## References

[1] Angelelli, E., Mansini, R., Vindigni, M., Exploring Greedy Criteria for the Dynamic Traveling Purchaser Problem, Central European Journal of Operations Research(Online Published), 2008.

[2] Boctor, F. F., Laporte, G., Renaud, J., Heuristics for the Traveling Purchaser Problem, Computers and Operations Research 30, pp. 491~504, 2003.

[3] Bontoux, B., Feillet, D., Ant Colony Optimization for the Traveling Purchaser Problem, Computers and Operations Research 35, pp. 628~637, 2008.

[4] Goldbarg, M. C., Bagi, L. B., Goldbarg, E. F. G., Transgenetic Algorithm for the Traveling Purchaser Problem, European Journal of Operational Research 199, pp. 36~45, 2008.

[5] Golden, B. L., Levy, L., Dahl, R., Two Generations of the Traveling Salesman Problem, Omega 9, pp. 439~445, 1981.

[6] Jain, R., Rivera, M. C., Moore, J. E., Lake, J. A., Horizontal Gene Transfer Accelerates Genome Innovation and Evolution, Molecular Biology and Evolution 20, pp. 1598~1602, 2003.

[7] Laporte, G., Riera-Ledesma, J., Salazar-Gonalez, J. J., A Branch and Cut Algorithm for the Undirected Traveling Purchaser Problem, Operations Research 51(6), pp. 142~152, 2003.

[8] Mansini, R., Tocchella, B., The Traveling Purchaser Problem with Budget Constraint, Computers and Operations Research 36, pp. 2263~2274, 2009.

[9] Margulis, L., Symbiosis in Cell Evolution, Microbial Communities in the Archean and Proterozoic Eon., W. H. Freeman, 1992.

[10] Miller C. E., Tucker, A. W., Zemlin R. A., Integer Programming Formulation of Traveling Salesman Problems, Journal of Association for Computing Machinery 7, pp. 32～329, 1960.

[11] Ong, H. L., Approximate Algorithm for the Traveling Purchaser Problem, Operations Research Letters 1, pp. 201～205, 1982.

[12] Pearn, W. L., Chien, R. C., Improved Solutions for the Traveling Purchaser Problem, Computers and Operations Research 25, pp. 879～885, 1998.

[13] Ramesh, T., Traveling Purchaser Problem, OPSEARCH 18, pp. 78～91, 1981.

[14] Riera-Ledesma, J., Salazar-Gonalez, J. J., A Heuristic Approach for the Traveling Purchaser Problem, European Journal of Operational Research 162, pp. 142～152, 2005a.

[15] Riera-Ledesma, J., Salazar-Gonalez, J. J., The Biobjective Traveling Purchaser Problem, European Journal of Operational Research 160, pp. 599～613, 2005b.

[16] Riera-Ledesma, J., Salazar-Gonalez, J. J., Solving the Asymmetric Traveling Purchaser Problem, Annals of Operations Research 144, 83～97, 2006.

[17] Singh, K. N., van Oudheusden, D. L., A Branch and Bound Algorithm for the Traveling Purchaser Problem, European Journal of Operational Research 97, pp. 571～579, 1997.

[18] Teeninga, A., Volgenant, A., Improved Heuristics for the Traveling Purchaser Problem, Computers and Operations Research 31, pp. 139～150, 2004.

[19] Voß, S., Dynamic Tabu Search Strategies for the Traveling Purchaser Problem, Annals of Operations Research 63, pp. 253～275, 1996.