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# Location Models for Public Distribution Centers Considering $NO_x$ Emissions under Traffic Congestion

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## ABSTRACT

Distribution centers managed by public authorities have been designed to achieve global optimization for efficient logistics and to maintain the urban environment. From the standpoint of social logistics, global optimization should be pursued considering both the environment and the efficiency of business logistics. For obtaining the optimal number and locations of the public distribution centers, we adopt the amount of $NO_x$ emitted by trucks as an environmental measure and propose mathematical programming models to minimize both logistics costs and $NO_x$ emissions under traffic congestion. These models are applied to the Tokyo metropolitan area and an appropriate policy for the number and locations of public distribution centers in that area can be proposed.

(和文要旨)

窒素酸化物の排出を考慮に入れた公共物流拠点の立地モデル

ロジスティクスは企業の生産・物流活動の効率化を図るビジネスロジスティクスから、交通渋滞、環境、エネルギー消費などの社会的視点をも考慮に入れたソーシャルロジスティクスへと進化してきている。公共物流拠点の立地場所を選定する際にも、従来の輸送費用最小化といった観点のみならず、トラック輸送に伴う排気ガス問題などの環境面についても考慮に入れなくてはならない。本研究では、総輸送費用や拠点の運営費用からなるロジスティクス費用と、渋滞による速度低下を考慮したトラック輸配送に伴う窒素酸化物の総排出量を最小化する物流拠点の数とその配置を求める数理計画モデル、およびその解法を提案する。さらに、このモデルを東京首都圏に適用し、物流拠点の適切な配置、総費用および窒素酸化物の総排出量を分析する。

## 1. INTRODUCTION

Recently, the concepts of social logistics or green logistics have been generalized for environmental management. In metropolitan areas, a most crucial issue is nitrogen oxide ($NO_x$) that is emitted by vehicular traffic, which is the main cause of air pollution such as photochemical smog. Diesel engines of trucks are especially heavy polluters. Various attempts have been made to minimize $NO_x$ emissions by trucks. Promoting modal shift and joint trucking, securing of cargoes for round trips, eliminating engine racing, enforcing travel at a steady speed, using more low-pollution vehicles, and thorough checking and maintenance of vehicles are good examples of them. Moreover, distribution centers managed by public authorities have been designed to achieve global optimization for efficient logistics and to maintain the urban environment. Public distribution centers are expected to have a positive impact on the urban environment because their use results in a reduction of $NO_x$ emissions from trucks. The achievements may be attributed to fewer vehicles and shorter delivery distances. However, if many trucks concentrate at a few centers, the amount of $NO_x$ emitted by trucks would increase because of heavy traffic congestion around these centers.

From the standpoint of social logistics, global optimization should be pursued considering both the environment and the efficiency of business logistics. In other words, we should reduce the volume of $NO_x$ emitted by trucks using public distribution centers, while simultaneously minimizing logistics costs. Logistics costs are made up of transportation costs from supply points to distribution centers, delivery costs from distribution centers to customers and operating costs at the centers.

In this study, we propose two mathematical programming models to minimize both logistics costs and $NO_x$ emissions under traffic congestion for obtaining the optimal number and locations of public distribution centers, and applied them to the Tokyo metropolitan area. Trucks discharge $NO_x$ during transport and delivery activities within the area. This amount of discharged $NO_x$ is proportional to vehicle-kilometers (the number of vehicles × transport and delivery distance) of trucks. In addition to that, idling trucks caught in traffic jams near distribution centers also emit an extra large amount of $NO_x$. Since $NO_x$ emissions form vehicles are closely related to their speed, we should consider truck speed or traffic congestion rather than vehicle-kilometers. If the number of centers were fewer, many trucks would crowd round the centers, and traffic jams would be more frequent. In consequence, the average speed of trucks would be reduced and the amount of $NO_x$ emissions would increase. A goal of our model is to reduce the volume of $NO_x$ emissions as well as the costs of logistics

We first present existing studies dealing with location problems of distribution centers, and then we demonstrate the procedural description in Section 2. A location model and an algorithm for obtaining solutions to minimize total logistics costs within the area are presented in 3.1. Solutions by the cost-minimizing problem are reconsidered in terms of the environment in 3.2. In 3.3, the other location model for minimizing the amount of $NO_x$ emissions is described. These models are applied to the Tokyo metropolitan area, and an appropriate policy for public distribution centers is proposed in Section 4. Finally, the optimum number and ideal locations for the public distribution centers from an environmental and logistics point of view can be obtained with our models

## 2. RELATED PROBLEMS AND PROCEDURAL DESCRIPTION

A wide variety of algorithms and applications for location problems have been proposed. Mirchandani-Francis [1] and Daskin [2] provide comprehensive reviews of discrete location problem methodologies including many exact and heuristic algorithms. Furthermore, public service location problems have been proposed, and they are known as *p*-median problems. ReVelle-Swain [3] proposed a relaxed linear programming algorithm, and Galvao [4] proposed a Lagrangian relaxation algorithm for such a problem. Though almost all of location problems emphasize logistics costs or public services, there are only a few studies dealing with location that focus on concave facility operating costs and the environment including $NO_x$ emissions by trucking and general traffic. Taniguchi et al. [5] and Yamada et al. [6] presented location models with cost-minimum, $CO_2$-minimum and multiobjective functions. Although they considered traffic congestion, they applied them to a rather small-scale location problem and did not deal with nonlinear operating costs. Yurimoto and Katayama [7] presented location models with cost-minimum and $CO_2$-minimum functions, but traffic congestion and $NO_x$ emissions were not dealt with.

We conducted a survey [8] on the use of public distribution centers by polling 531 firms in the Tokyo metropolitan area. The survey indicates that approximately 60% of the participants wanted to make use of public distribution centers. To be precise, 70% of 167 wholesalers, 56% of 199 retailers, and 54% of 165 manufacturers are expecting public distribution centers to be established. According to the survey, most of the firms were interested in the availability of land and use fees for distribution centers.

When we consider the impact of public distribution centers on the environment, the sum of the vehicle-kilometers in the metropolitan area should be minimized to reduce truck $NO_x$ emissions. In order to do that, the number of distribution centers could be increased so as to decrease the total delivery distances. However, many companies tend to prefer to reduce the number of distribution centers to minimize stock volumes and costs.

We asked the survey participants about their views for the future regarding the number of distribution centers. Fifty-nine percent of the firms predicted a gradual integration while only nine percent predicted a more immediate increase in the number of distribution centers.

Furthermore, most companies actually do their best to reduce logistics costs rather than the sum of vehicle-kilometers or $NO_x$ emissions. Transportation costs from supply points to distribution centers, delivery costs from distribution centers to customers and operating costs in the centers are included in these logistics costs. As the total logistics costs within the area are summed up by each individual case, we first deal with the cost-minimizing problem, and then consider the $NO_x$-minimizing problem.

The following steps are required:

1. Build a location model and an algorithm for minimizing logistics costs, which are made up primarily of transportation, delivery and operating costs.
2. Evaluate solutions to this cost-minimizing problem by measuring the amount of $NO_x$ emissions.
3. Build a location model and an algorithm for minimizing the amount of $NO_x$ emissions within the area.
4. Evaluate solutions to this $NO_x$-minimizing problem by measuring logistics costs.
5. Find the appropriate number and locations of public distribution centers, which show the lower logistics costs within the certain level of $NO_x$ emissions by comparing and reconsidering the solutions of both problems.

These procedures are conducted in and applied to the Tokyo metropolitan area.

## 3. MODEL AND ALGORITHM

### 3.1 Cost-Minimizing Problem (CMP)

We first show a mathematical programming model for minimizing total logistics costs [7].

The following set of assumptions is made in order to formulate the model:

1. Supply points, demand points and candidate distribution center sites are given as a set of nodes.
2. Distribution centers can handle unlimited amounts of any kind of commodities.
3. The amounts of supply and demand at all nodes are given.
4. All goods from supply points are transported to demand points via a distribution center.
5. Transported volume from supply points to demand points is given.
6. Operating costs at distribution centers are increased nonlinearly by the amount of goods handled.

Moreover, we define the following notation to formulate this model. *K* is the commodity set, *S* is the supply point set, *F* is the candidate distribution center set and *D* is the demand point set. $x_{ij}^k$ is a variable, which is the amount of transport of commodity *k* from supply node *i* to center *j*. $z_{jl}^k$ is a variable, which is the amount of delivery of commodity *k* from center *j* to demand node *l*. Let $y_j$ be a binary variable, which is equal to one if candidate center *j* is located or zero otherwise. *u* is the number of public distribution centers. $d_{il}^k$ is the demand of commodity *k* transported from supply node *i* to demand node *l*; $c_{ij}^k$ is the transportation cost per volume, and $e_{jl}^k$ is the delivery cost per volume. $f_j$ is the non-linear operating cost function at center *j*, and $b_j^k$ is the amount of demand of commodity *k* handled at center *j*. *M* is a very large arbitrary number.

The problem is to determine the number, locations of public distribution centers and the volume of transport or delivery, which will minimize total logistics costs. Using the above-mentioned notation, an integer nonlinear mathematical programming model is formulated as follows:

$$\begin{aligned} \text{minimize} \quad & \sum_{i\in S}\sum_{j\in F}\sum_{k\in K} c_{ij}^k x_{ij}^k + \sum_{j\in F}\sum_{l\in D}\sum_{k\in K} e_{jl}^k z_{jl}^k \\ & + \sum_{j\in F} f_j\left(\sum_{k\in K} b_j^k\right) y_j \end{aligned} \tag{1}$$

$$\text{subject to} \sum_{j\in F} x_{ij}^k = \sum_{l\in D} d_{il}^k \qquad i\in S, k\in K \tag{2}$$

$$\sum_{j\in F} z_{jl}^k = \sum_{i\in S} d_{il}^k \qquad l\in D, k\in K \tag{3}$$

$$\sum_{i\in S} x_{ij}^k = \sum_{l\in D} z_{jl}^k = b_j^k \qquad j\in F, k\in K \tag{4}$$

$$x_{ij}^k \le M y_j \qquad i\in S, j\in F, k\in K \tag{5}$$

$$z_{jl}^k \le M y_j \qquad j\in F, l\in D, k\in K \tag{6}$$

$$\sum_{j\in F} y_j = u \tag{7}$$

$$x_{ij}^k \ge 0 \qquad i\in S, j\in F, k\in K \tag{8}$$

$$z_{jl}^k \ge 0 \qquad j\in F, l\in D, k\in K \tag{9}$$

$$y_j \in \{0,1\} \qquad j\in F \tag{10}$$

$$u \in integer \tag{11}$$

Equation (1) is the objective function, which should be minimized. The first term in this equation represents the transportation cost from supply points to the distribution centers. The second term is the delivery cost from distribution centers to demand points. The third term is the operating cost at these centers, which depends non-linearly on the volume of goods handled. Equations (2), (3), and (4) are the conservation constraints; (2) is the one from supply points to distribution centers; (3) is the one from distribution centers to demand points, and (4) is the one at distribution centers respectively. Equations (5) and (6) are the forcing constraints, which show that any supply or demand must not be transported to center *j* or delivered from center *j*, if the center is not located in node *j*, that is, $y_j=0$. Equation (7) shows the relationship between $y_j$ and *u*. The rest of the constraints, (8), (9), (10) and (11) denote non-negative, zero-one or integer conditions.

Finding an optimum solution to this problem is not easy because of its integrality and nonlinearity. Therefore, Random Multi-start Limited Neighborhood (RMLN) search algorithm for obtaining a good approximate solution is proposed for this type of problems [7].

Given the number of public distribution centers and their temporal locations initially, each demand node is assigned to the center node with the lowest delivery cost, since we assume that distribution centers are uncapacitated and delivery costs should be minimized. A created set of nodes assigned to the same center forms a new territory for the center. We expect the new center serving each demand node in the territory to be located at the optimal node, minimizing the total cost in each territory. This problem is known as the one-median problem. We find these new locations by a simple enumeration method. Then, we replace current locations with new locations. While the total cost is reduced, the procedure is repeated to find new territories and new center locations and to replace the old ones with new ones. This method is a neighborhood search improvement algorithm.

In the neighborhood search, as an enumeration of every node within each territory brings about a considerable change in territories and center locations, the approximate total cost in the one-median problem might often be inaccurate. Therefore, we limited the enumeration to a certain number of nodes with lower delivery costs rather than including all nodes in the one-median problem. Since the solution obtained by the neighborhood search is strongly dependent on its initial solution, we should provide a large number of random initial locations and repeat the neighborhood search according to a variety of initial location. Furthermore, as the number of public distribution centers could vary within the appropriate range up to the upper limit, we repeat the neighborhood search for every number of the center. In this way, we can obtain the best number of public distribution centers and locations from among all approximate solutions

### 3.2 Estimation of the amount of $NO_X$ emissions

Solutions of CMP are evaluated in terms of the amount of $NO_X$ emissions in order to give consideration to environmental issues. Now we assume that the amount of $NO_X$ emissions is a nonlinear function of the number of vehicles around the center. In order to estimate the amount of $NO_X$ discharged by trucks during transportation and delivery activities within the area, we substitute solutions in CMP into the following formula and evaluate the amount of $NO_X$ emissions.

$$\sum_{i\in S}\sum_{j\in F}\sum_{k\in K} m_{ij}^k x_{ij}^k g_{ij}{}^k\left(\mathbf{x}_j,\mathbf{z}_j\right)+\sum_{j\in F}\sum_{l\in D}\sum_{k\in K} n_{jl}^k z_{jl}^k h_{jl}{}^k\left(\mathbf{x}_j,\mathbf{z}_j\right) \tag{12}$$

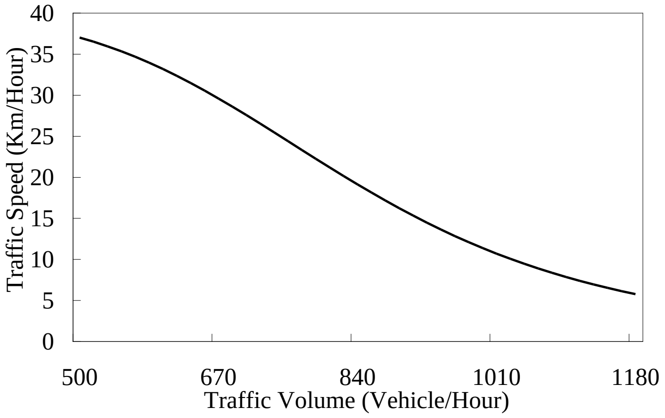

Figure 1. Traffic Volume versus Traffic Speed
(Link Capacity=1000)

where, function $g_{ij}{}^k$ is the volume of $NO_X$ emissions per vehicle from supply node $i$ to distribution center $j$ of commodity $k$, and function $h_{jl}{}^k$ is the volume of $NO_X$ emissions per vehicle from distribution center $j$ to demand node $l$ of commodity $k$. $m_{ij}{}^k$ is the number of vehicles per volume transported from $i$ to $j$ of $k$, and $n_{jl}{}^k$ is the number of vehicles per volume delivered from $j$ to $l$ of $k$. $\mathbf{x}_j$ is the vector $(x_{1j}{}^k, x_{2j}{}^k, \cdots)$ and $\mathbf{z}_j$ is the vector $(z_{j1}{}^k, z_{j2}{}^k, \cdots)$ , which indicate the traffic volume in and out of center $j$.

The first term in formula (12) is the amount of $NO_X$ emitted during transportation activities from supply points to distribution centers. The second term is the amount of $NO_X$ emitted during delivery activities from distribution centers to demand points. The amount of $NO_X$ emissions is closely related to the traffic speed, and the traffic speed is related to traffic congestion or the number of vehicles within an area. Therefore, $g_{ij}{}^k$ and $h_{jl}{}^k$ can be presented as functions of vectors $\mathbf{x}_j$ and $\mathbf{z}_j$.

Traffic volume around the center that would be established, could be estimated based on the number of vehicles from $\mathbf{x}_j$ and $\mathbf{z}_j$. A common approach to modeling the total travel time on a link as a function of traffic volume on that link is the so-called Bureau of Public Roads (BPR) function [9]. Using this function, the speed per hour of trucks at a distance $u_j$ from center $j$ is shown as follows.

$$v_j = 1/t\left[1+\alpha\left\{X_j\left(\mathbf{x}_j,\mathbf{z}_j,u_j\right)/C\right\}^{\beta}\right] \tag{13}$$

where, $v_j$ is the traffic speed at a distance of $u_j$ from the center $j$. The denominator of this formula shows the BPR function. $t$ is free-traffic travel time per unit distance. $X_j$ which is the function of $\mathbf{x}_j$, $\mathbf{z}_j$ and $u_j$ , denotes the traffic volume at a distance of $u_j$ from the center $j$. $C$ is link capacity and $\alpha$, $\beta$ are constants. Figure 1 shows the relationship between traffic volume and traffic speed.

As the speed of the truck decreases, a large amount of $NO_X$ is discharged due to engine racing and idling. The volume of $NO_X$ emissions can be obtained from the speed per hour of trucks within a unit sphere of the center by using the empirical function derived by the Tokyo Bureau of Environment [10]. This function is shown as follows.

$$E_p = \gamma_p + \delta_p v + \varepsilon_p v^2 + \varsigma_p v^3 + \eta_p / v \qquad (14)$$

where, $E_p$ is the volume of $NO_X$ emissions per vehicle-kilometer, $v$ is the speed per hour of a vehicle, $\gamma_p$, $\delta_p$, $\varepsilon_p$, $\zeta_p$ and $\eta_p$ are parameters, which are peculiar to the type $p$ of the vehicle. Figure 2 shows the relationship between traffic speed and $NO_X$ emissions for a normal-size truck and a passenger car.

Consequently, the function $g_{ij}^k$ and $h_{jl}^k$ are expressed as formula (15) and (16).

$$g_{ij}^k(\mathbf{x}_j, \mathbf{z}_j) = \int_0^{S_{ij}} E_k^g(\mathbf{x}_j, \mathbf{z}_j, u_j)\,du_j \qquad (15)$$

$$h_{jl}^k(\mathbf{x}_j, \mathbf{z}_j) = \int_0^{S_{jl}} E_k^h(\mathbf{x}_j, \mathbf{z}_j, u_j)\,du_j \qquad (16)$$

where, $E_k^g$ and $E_k^h$ are the amount of $NO_X$ emissions during transport and delivery activities at a distance $u_j$ from center $j$ of commodity $k$, respectively. $S_{ij}$ is the distance between supply node $i$ and center $j$, and $S_{jl}$ is the distance between center $j$ and demand node $l$. Then $g_{ij}^k$ can be calculated as the sum of $NO_X$ emissions from supply node $i$ to center $j$, and $h_{jl}^k$ as the sum of $NO_X$ emissions form center $j$ to demand node $l$.

### 3.3 $NO_X$-Minimizing Problem ($NO_XMP$)

As well as the location model for CMP, we can easily formulate a model for minimizing the volume of $NO_X$ by using an estimation of the amount of $NO_X$ emissions form trucks.

Let the objective function of this problem be the amount of $NO_X$ emissions that should be minimized. This function is the same as in the formula (12) used for evaluating the amount of $NO_X$ emissions in CMP. The constraints for minimizing $NO_X$ are also the same as those used for CMP.

We can formulate $NO_X$-minimizing problem ($NO_XMP$) as the following integer nonlinear mathematical programming model:

$$\begin{aligned} \textit{minimize} \ & \sum_{i\in S}\sum_{j\in F}\sum_{k\in K} m_{ij}^k x_{ij}^k g_{ij}^k(x_j, z_j) \\ & + \sum_{j\in F}\sum_{l\in D}\sum_{k\in K} n_{jl}^k z_{jl}^k h_{jl}^k(x_j, z_j) \end{aligned} \qquad (17)$$

*subject to* (2)〜(11)

This is the same as CMP, except for the objective function in which we substitute the amount of $NO_X$ emissions for the total logistics costs. Therefore, we can adopt the RMLN algorithm to obtain a good approximate solution. In the RMLN algorithm for CMP, we substitute the amount of $NO_X$-emissions for the logistics costs.

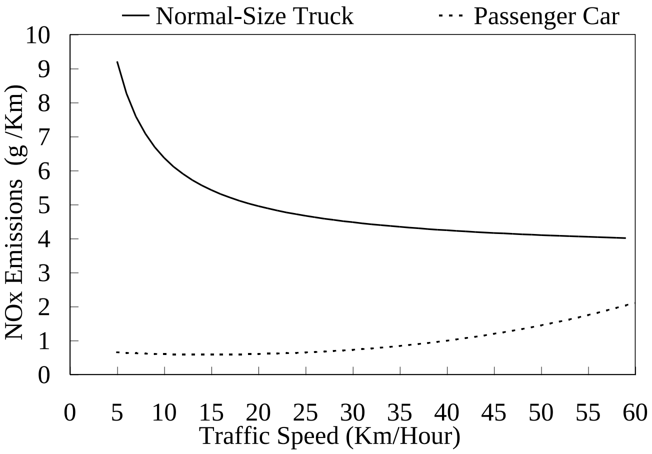

Figure 2. Traffic Volume versus NOx Emissions

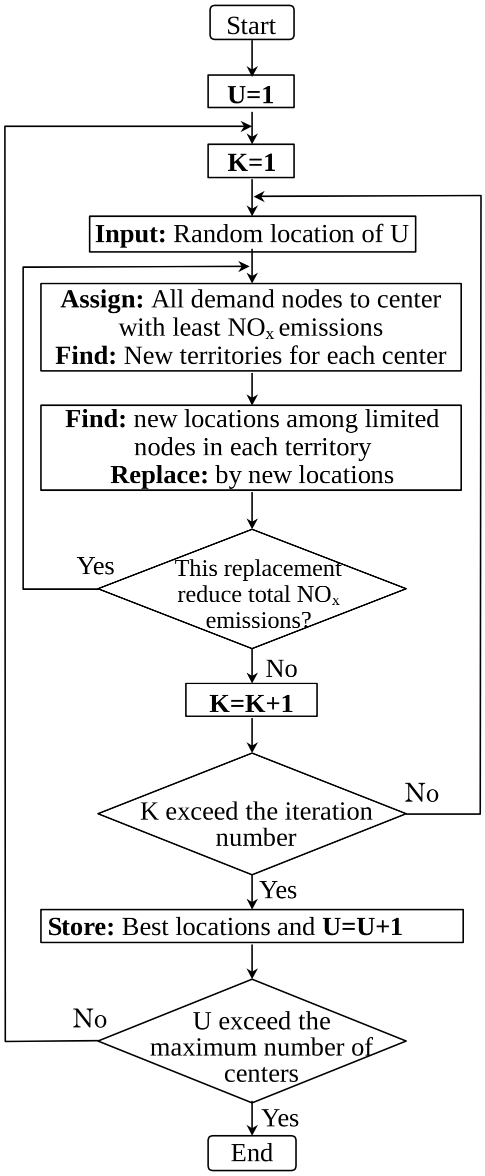

Figure 3. RMLN algorithm

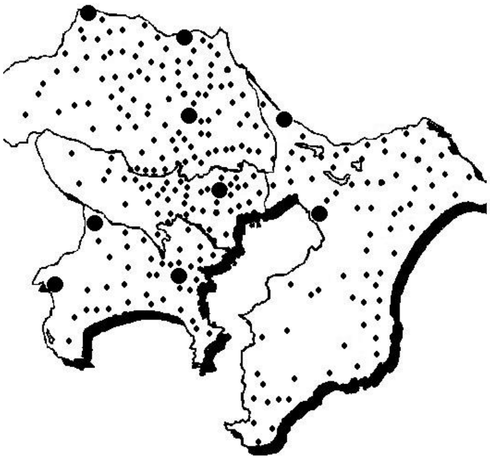

Figure 4. Locations of demand and supply points

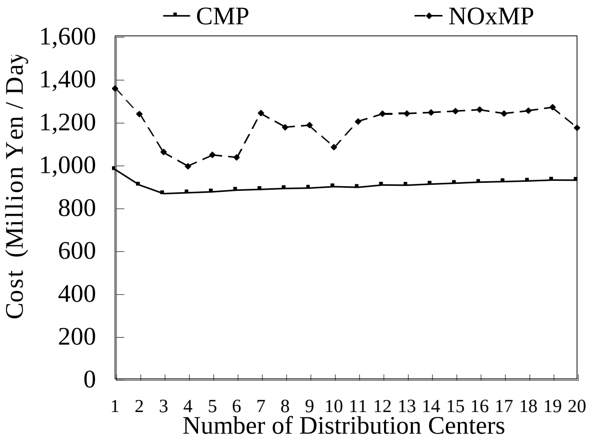

Figure 5. Costs Versus Number of Distribution centers

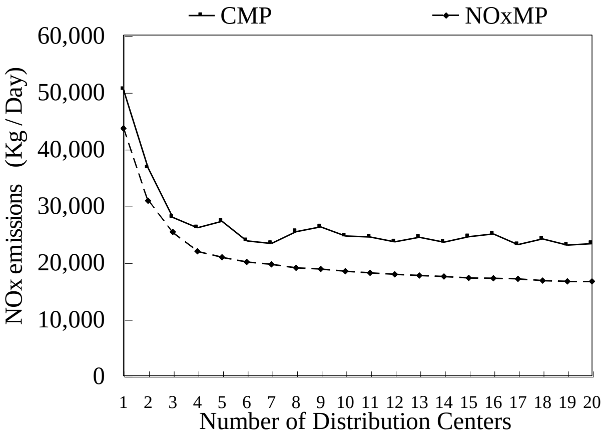

Figure 6. NOx Emissions Versus Number of Distribution

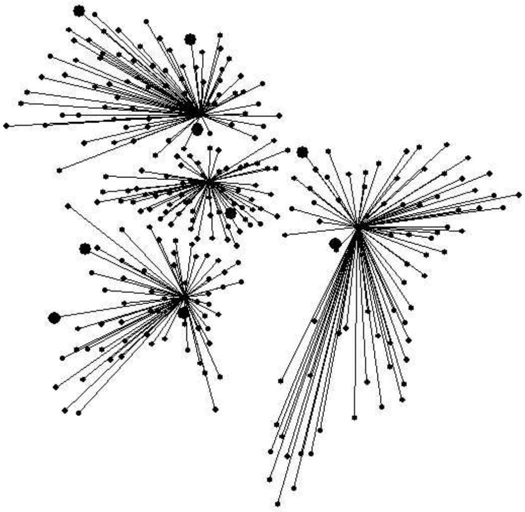

Figure 7. Locations of four centers and their territories

Figure 3 shows a flowchart of RMLN algorithm for $NO_X$MP. In Figure 3, U denotes the current number of centers and has the range from one to maximum number of centers. K denotes the current iteration number at U centers and has the range from one to maximum iteration number. Within these ranges, we repeat the neighborhood search by using random initial locations.

When we substitute solutions in $NO_X$MP into formula (1), we can evaluate the total logistic costs for these solutions.

## 4. APPLICATIONS

We apply our models to the Tokyo metropolitan area. The Tokyo metropolitan area consists of the Tokyo metropolis and the Kanagawa, Chiba, and Saitama prefectures. We divided this area into 283 demand points, which are located at the centers of the cities, towns and villages comprising the Tokyo metropolitan area. It is assumed that the distribution centers are to be located somewhere among these demand nodes. The number of supply points is nine, and they are located at the entrance nodes outside the Tokyo metropolitan area and in nodes with main sources within that area. Figure 4 illustrates locations of supply points and demand points in the Tokyo metropolitan area.

We deal with the following eight kinds of commodities: agricultural, marine, forest, metal, machine, chemical, light industrial, other industrial and special. Demand data from every supply point to every demand point by commodity, are obtained from a Goods Flow Survey of the Tokyo metropolitan area (1997).

Parameters used in our model are shown as follows; $\alpha$

=2.62, $\beta$=5, $C$=1000 and $X_j = (\sum_i x_{ij} + \sum_l z_{jl})/u_j + \theta$ in formula (13). $\theta$ is the average number of motor vehicles except trucks using center $j$, and let $\theta$ be 825 in this study. $\gamma_p$ =3.53, $\delta_p = \varepsilon_p = \zeta_p$=0, and $\eta_p$ =28.4 in formula (14). These values are experimentally adopted in many studies on road management in Japan [10] [11].

The maximum number of the public distribution center is 20, the maximum iteration number of random initial locations is 100,000 in the RMLN algorithm. Some other detail assumptions and input data for this application are shown in [7] [12].

Using these data, we solved CMP and $NO_X$MP by the RMLN algorithm. Figure 5 shows the comparison of the total logistics costs between both problems. A solid line in Figure 5 denotes the logistics costs, which consist of values of objective functions calculated corresponding to the number of center in CMP. A broken line denotes the logistics costs, which are measured to evaluate solutions in $NO_X$MP. The total costs in CMP decrease until there are three centers and gradually increase from there on. The minimum cost in $NO_X$MP is obtained when there are four centers. As a matter of course, the total logistics costs in $NO_X$MP are higher than that in CMP. In case of three centers, the difference in the total costs accounts for 22.5%, 14.2% in case of four centers and 26.3% in case of 20 centers.

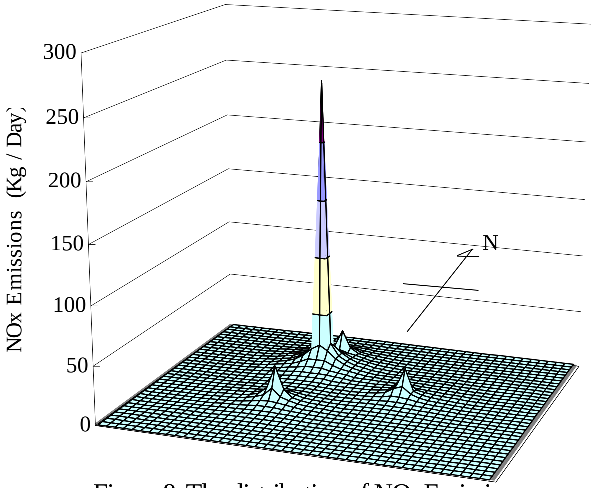

Figure 8. The distribution of $NO_x$ Emissions of four centers for CMP

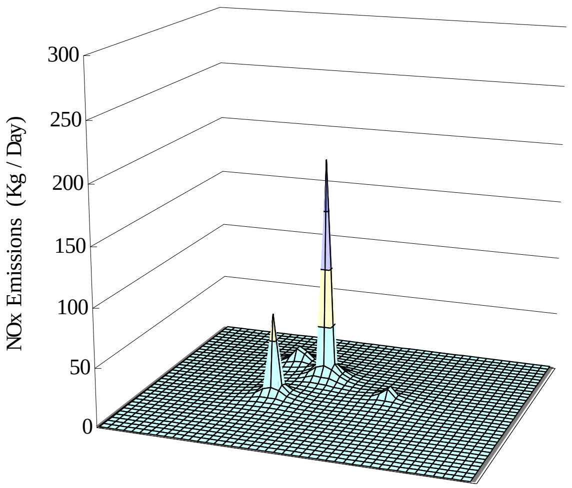

Figure 9. The distribution of $NO_x$ Emissions of four centers for NOxMP

Figure 6 shows the comparison of the amount of $NO_X$ discharged by trucks between CMP and $NO_X$MP. In both problems, it is clear that the amount of $NO_X$ emissions decreases sharply until there are four centers and the amounts seem to remain stable when there are more than four centers. The amounts of $NO_X$ emissions in $NO_X$MP are lower than that in CMP. The difference in the amount of $NO_X$ emissions in both problems accounts for 9.1% in case of three centers, 15.9% in case of four centers and 28.6% in case of 20 centers. These results suggest that if all companies do their best to reduce $NO_X$ emissions rather than their logistics costs, the amount of $NO_X$ emissions could be reduced by about 16% to 29%.

The number of public distribution centers should be determined based upon both total logistics costs and the amount of $NO_X$ emissions. In terms of logistics costs, the optimal number of centers is three. However, the difference in the total costs between three and four centers is very small (0.5%), as shown in Figure 5. From the standpoint of the amount of $NO_X$ emissions, it is better as there are many centers because of fewer concentrations of vehicles and shorter delivery distances. As shown before, the amount of $NO_X$ emissions decreases sharply until there are four centers and the amounts seem to remain stable when there are more than four centers. In the end, the appropriate number of public distribution centers which shows the low logistics costs within the certain level of $NO_x$ emissions is four in this case.

Figure 7 illustrates locations of four centers and their territories. These locations are on the outskirts of Tokyo 23 Wards, Yokohama, Chiba and Saitama City, and moreover on access roads to expressways from the outside of the Tokyo Metropolitan area. Furthermore these centers are located relatively near the existing physical distribution centers (Keihin,

Itabashi, Kasai and Adachi) that had been planned by the Metropolitan Government. Figure 8 shows the distribution of $NO_X$ emissions in the Tokyo metropolitan area for CMP. Figure 9 shows the distribution of $NO_X$ emissions of the four centers for $NO_X$ MP.

Although it is difficult to evaluate the validity of our models properly, the results obtained agreed approximately with those expected, since they are consistent with some locations of the actual large-scale distribution centers and the relationship of the number of centers to the logistics costs and the amount of $NO_X$ emissions is also persuasive. The authorities concerned could examine the solutions of our two models and make use of them for their decision-making in regional planning.

## 5. CONCLUSION

So far, we have outlined our models for the optimal number and location of public distribution centers and showed the applications to the Tokyo metropolitan area. The applications of our model have enabled us to suggest an appropriate policy for public distribution centers in this area.

Public distribution centers will be a new attempt to achieve global optimization for the community. However, there are still many problems requiring solution before these distribution centers are widely used, such as the diesel trucks spewing out exhaust fume like $NO_X$ and $CO_2$, an over-concentration of population and goods into the metropolitan area, etc. These and other problems will have to be solved by the joint efforts of the government, local autonomous bodies and industries concerned. Enterprises should take the environmental issues into consideration to achieve successful social or green logistics, when planning strategy for logistics.

The optimum number and ideal locations for the distribution centers from an environmental, logistics and economics point of view can be obtained with our model. A foreseeable extension of this study would be to investigate the methods of integrating both CMP and $NO_X$MP.

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