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PREDICTION OF REGIONAL ROAD FLOW IN CONTAINER TRANSPORTATION BASED ON ORIGIN-DESTINATION MATRIX ESTIMATION

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Abstract. *This paper proposes an approach to predicting the impact of increasing port container transportation on the metropolitan traffic network around a port city. First, we use the origin-destination (OD) matrix estimation method to derive all of the network road traffic considering the incomplete information of vehicle traffic flow and the OD of container transportation. Next we propose a traffic flow superposition method that combines OD matrix estimation and traffic assignment considering the supply-demand relationship between the port and the container logistics around the city. The degree of influence is estimated based on the final calculated total road volume, and provides a basis for measures and policies to cope with traffic congestion on the road network. Specific case studies show that this method can effectively analyze the superposition of multiple vehicle flows with incomplete road network information.*
Keywords: Traffic network, Container transportation, Traffic assignment, OD matrix estimation

1. Introduction.

Recently, the yearly increasing throughput of container terminals has brought heavy traffic pressure to urban roads around ports as the increase in container traffic volume easily leads to congestion on urban roads and serious environmental issues. Therefore, it is highly important and significant to effectively assess the impact of container traffic growth on the traffic network around the port city for effective allocation of logistics resources, assignment of transport modes, and relief of road congestion. To solve this problem, it is necessary to solve two issues: the first is to forecast the container traffic volume on the metropolitan traffic networks, and the second is to estimate the total traffic volume with mixed traffic flow on the traffic network.

First, under general circumstances, the method on traffic volume forecasting is to form OD matrices of the container traffic by traffic surveys, and the traffic volume information for each road is determined based on road traffic assignment. Thus, the total predicted traffic volume is obtained. The present relevant studies have focused on the following two fields. The first is the study of data accuracy to ensure prediction accuracy. Hazelton inferred the OD matrix from a single observation of a set of network link flows and

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demonstrated that the two solutions corresponding to reconstructing the actual number of OD trips [1,2]. Ma and Qian studied a new theoretical framework to estimate the mean and variance/covariance matrix of OD demand and to reduce the error of estimators [3]. Foulds et al. proposed an OD matrix estimation method based on fuzzy sets [4]. And the second field is the study of OD models and algorithms. Gao and Si presented an optimization model and algorithm for augmenting the user equilibrium (UE) problem and later proposed a bi-level planning model and algorithm for estimating OD traffic volume from link traffic flows [5]. García and Verastegui pointed out that the demand adjustment problem (DAP) method integrated the OD matrix estimation and the network equilibrium assignment into one process and provided the DAP column generation algorithm [6]. García and Marín studied the characteristics of the calibration and demand adjustment model (CDAM) based on bi-level programming with a heuristic column generation algorithm [7]. Tympakianaki et al. proposed a modification of the simultaneous perturbation stochastic approximation (SPSA) algorithm [8]. Tesselkin et al. studied the method of estimating an OD matrix using observational data on traffic flows based on the Markov chain theory [9]. Caggiani et al. pointed out an OD matrix estimation method based on traffic counts with generalized least square estimators [10]. The above method not only requires mastering traffic information on all roads but is time-consuming and laborious in the workload of an actual traffic survey. Instead of this method, the OD matrix estimation method can be used to accurately obtain the predicted traffic value of the road network in case that only part of the traffic information is mastered.

Moreover, for the application of the OD matrix estimation, some analysis of the traffic flow impact on transport networks includes the following studies. Parola and Sciomachen [11] used the OD matrix estimation to analyze the potentiality of land infrastructure for an intermodal transport network by evaluating the possible future growth of container flows. And Milevich et al. [12] used the same method to analyze the planned road network development on the dynamics of the automobile transportation system during matches taking place in a newly built stadium. Other topics about this method application include: the impact of a public bicycle-sharing system on urban public transport networks [13], and the impact of traffic congestion on distribution costs [14], and on CO_2 emission levels of urban freight distribution networks [15].

Nonetheless, there are few works dealing with the prediction of regional road flow in container transportation based on OD matrix estimation method. And because of the complexity of urban traffic around ports, the estimation effect of some existing methods is not high. Therefore, this paper proposes an OD matrix estimation method to evaluate the impact of multimodal transport from container seaports. The structure of this paper is arranged as follows. Section 2 describes the problem, followed by analysis and construction of model methods in Section 3. Section 4 illustrates a case study, and analyzes the results and Section 5 presents the conclusions of the study.

2. **Description of the Problem.**

The network of freight roads in a general port city and its surroundings is represented by a graph $N = (V, R, W)$. $V = \{v_i | i = 1, 2, \ldots, n\}$ is the node set of the network, and n is the number of network nodes. R is a set of freight roads, $R = \{r_k = v_{i(k)j(k)} = (v_{i(k)}, v_{j(k)}) | k = 1, 2, \ldots, nl; v_{i(k)}, v_{j(k)} \in V, i \neq j\}$, nl is the number of roads, and there are corresponding origins-destinations (v_i, v_j) for each of the directed links $v_{ij} \in R$. $W = (C, L, S)$ is the set of rights for the set R, C is the link capacity, L is the link length, and S is the link speed limit. At the same time, the urban road network is divided into several districts $A = \{a_u | u = 1, 2, \ldots, m\}$. The number of nodes contained in each district a_u is n_u, and the node set is $V_u = \{v_p^u | p = 1, 2, \ldots, n_u\} \in V$; in link set $R_u = \{r_q^u = v_{i(q)j(q)}^u = (v_{i(q)}^u, v_{j(q)}^u) | q = 1, 2, \ldots, k_u; v_{i(q)}^u, v_{j(q)}^u \in V, i \neq j\} \in R$, and

k_u is the number of links. These districts should meet the following conditions:

$$V = \sum_{i=1}^{n_u} v_i^u, \quad u = 1, 2, \ldots, m \tag{1}$$

$$R = \sum_{q=1}^{k_u} v_{i(q)j(q)}^u, \quad u = 1, 2, \ldots, m \tag{2}$$

$$V \in V_1 \cup V_2 \cup V_3 \cup V_4 \cup \ldots \cup V_m \tag{3}$$

$$V_1 \cap V_2 \cap V_3 \cap V_4 \cap \ldots \cap V_m = \emptyset \tag{4}$$

First, there are general vehicles including private cars, buses and minivans in the urban traffic network around the port. Assume that the OD matrix of vehicles in the city is OD_g, the total traffic volume during the observation period T is Qg, and the unit is PCU (Passenger Car Unit). Therefore, there are the following Formulas (5) and (6):

$$OD_g = \sum [g_{ij}]_{n\times n} \tag{5}$$

$$\sum_j g_{ij} = Og_i, \quad \sum_i g_{ij} = Dg_j, \quad \sum_i \sum_j g_{ij} = \sum_i Og_i = \sum_j Dg_j = Qg \tag{6}$$

Among these values, Og_i is the traffic volume that occurs at origin point $v_i \in V^O$ within the T period, and Dg_j is the traffic volume that is attracted by the destination node $v_j \in V^D$ in the T period. g_{ij} indicates the traffic volume of vehicles in a general city from node v_i to node v_j within the T period. V^O and V^D are, respectively, the set of origins and destinations in the general urban area traffic network. Second, there are a certain number of port transportation vehicles in the transportation network. Assume that a node in the network where the container port is located in P, is $P \in V$. Assume that container traffic at node P during the observation period T is Qc, and the unit is TEU. According to the different directions of container transportation import and export, Qi and Qe, respectively, indicate the quantity of imported and exported containers, $Qc = Qi + Qe$. For the container traffic flow to and from the port, the freight transport OD matrix formed by origin point v_i and destination point v_j of container supply and demand is defined as follows:

$$OD_c = \sum [d_{ij}]_{n\times n} \tag{7}$$

$$\sum_j d_{ij} = Oc_i, \quad \sum_i d_{ij} = Dc_j, \quad \sum_i \sum_j d_{ij} = \sum_i Oc_i = \sum_j Dc_j = Qc \tag{8}$$

In the formulas, d_{ij} indicates the container traffic from node v_i to node v_j in period T, Oc_i is the amount of exported containers at node v_i in period T, and Dc_j is the amount of imported containers at node v_j in period T.

The freight road network in the port cities and the surrounding areas studied in this paper contains both general city vehicles and port container traffic flow, so constitute the traffic flow and direction of the entire network. The specific calculation is shown in Formulas (9) and (10):

$$OD = \sum [z_{ij}]_{n\times n} = \sum [g_{ij} + d_{ij}]_{n\times n} \tag{9}$$

$$\sum_j (g_{ij} + d_{ij}) = Oz_i, \sum_i (g_{ij} + d_{ij}) = Dz_j, \sum_i \sum_j z_{ij} = \sum_i Oz_i = \sum_j Dz_j = Qz \tag{10}$$

where z_{ij} is the traffic flow from nodes v_i to v_j in period T. Oz_i is the traffic flow from node v_i in period T, Dz_j is the traffic flow to node v_j in period T, and Qz is the total traffic flow in the observation period T.

3. Problem Analysis and Method Construction.

The problem studied in this paper is how to analyze and evaluate the impact of port container transport on the traffic network around the city while only mastering the container OD matrix and a fraction of road traffic. Among the relevant parameters, although it is possible to obtain the traffic capacity of each link, the length of the link, the speed limit, and the instantaneous traffic information of some roads, it is very difficult to obtain complete real-time traffic information for all roads R of the entire traffic network. Therefore, we attempt to solve the problem from two aspects. One situation is that the throughput and the flow information between the port P and various regions are relatively easy to know, and the appropriate traffic assignment method is applied to solving the problem. Another situation is that the road traffic information in an ordinary city cannot be fully known, and the OD matrix estimation method is used to solve the road traffic forecasting problem.

3.1. Traffic assignment.

The traffic assignment is based on the known OD matrix. According to the actual situation, the traffic is assigned to each road in the network following certain rules, and the traffic flow for each road is obtained. Since there are many roads from the starting point to the destination, how to properly and correctly assign the traffic to each road is a problem that needs to be solved in traffic assignments.

The commonly used methods of assignment include the all or nothing method, incremental assignment, capacity restraint assignment, the system optimum method and the UE method [2,7-9]. The first method is to assign all of the traffic between OD points to a unique path and is less realistic. The contradiction between traffic volume and running time leads to evaluation index error in the second method and later increases the error of the assignment result to a certain extent. The largest problem of the third method is that it is not easy to achieve a convergent equilibrium result. The limitation of the fourth method is that users are all informed of the optimal route, which is clearly too idealistic. However, the UE method adopts an iterative process to obtain an equilibrium solution. The traffic volume of the link is recalculated in each iteration and the capacity and running time are also considered.

In summary, the UE method is more reasonable than other methods. The port container transportation network method can be adopted under the premise of knowing the container transport OD matrix, which is used to assign the container traffic to different paths according to certain assignment rules (such as the principle of the shortest path and the principle of user balance), and thus obtain freight traffic on various roads.

3.2. OD matrix estimation.

The OD matrix estimation can accurately predict road network traffic when only partial traffic information is available. The method determines the estimated value by combining the collected traffic network data, traffic volume, small-scale or partial OD trip surveys and other available traffic information. Let V_a be the traffic of link a, T_{ij} is the number of trips between districts i and j, and P_{ij}^a is the ratio of trips between the districts i and j through link a.

$$V_a = \sum_{ij} T_{ij} P_{ij}^a \quad (0 \leq P_{ij}^a \leq 1) \tag{11}$$

The OD matrix estimation includes single-path OD matrix estimation (SPME) and multi-path OD matrix estimation (MPME). The SPME method first obtains the optimal single path between origins and destinations through traffic assignment, and later corrects and updates the OD matrix by comparing the assigned and observed traffic volume. The method strives to predict the OD matrix for the maximum traffic volume of the optimal road between OD pairs. The objective function is:

$$\min_{T_{ij}} = \left[f_1 \left(\overline{\overline{t_{ij}}}, \overline{\overline{T_{ij}}}, \overline{V_a}, \overline{T_a} \right) \right] \tag{12}$$

where f_1 is the new inverse matrix, $\overline{\overline{t_{ij}}}$ is the initial trip matrix of traffic district i to j, $\overline{\overline{T_{ij}}}$ is the new trip matrix, $\overline{V_a}$ is the traffic volume observed on link a, $\overline{T_a}$ is the road traffic volume assigned to link a according to the traffic assignment model $\overline{T_a} = f_2(\overline{\overline{T_{ij}}})$, and f_2 is the traffic assignment model.

In order to make the traffic observations of the optimal path between OD pairs correspond to the assigned traffic volume, one still needs to further calculate the expected traffic volume of the observed link. The specific calculation is shown in Equation (13):

$$T_{(E)ija} = \frac{V_a}{T_a} \cdot t_{ij} \tag{13}$$

Among these values, $T_{(E)ija}$ is the expected traffic volume on the link from traffic districts i to j. As shown in the following Formula (14), each optimal path is checked one by one using the arithmetic mean in the maximum likelihood method:

$$T_{ij} = \frac{1}{N_{a\in(\tau,r)}} \cdot \sum_{a\in(\tau,r)} T_{(E)ija} \tag{14}$$

N is the traffic volume of the route, and τ is the route selection set along the optimal route r.

One can also use the harmonic mean method to test the link and its assigned traffic volume, as shown in Formula (15).

$$\min_{T_{ij}} = \left[Err_{sqr} = \frac{1}{N_{a\in(\tau,r)}} \cdot \sum_{a\in(\tau,r)} \frac{\left(T_{(E)ija} - T_{ij}\right)^2}{T_{(E)ija}} \right] \Rightarrow T_{ij} = \frac{N_{a\in(\tau,r)}}{\sum_{a\in(\tau,r)} \frac{1}{T_{(E)ija}}} \tag{15}$$

The MPME method is obtained by upgrading the SPME method. This method needs to determine the selection of multiple optimal paths between OD pairs. In other words, the assigned flows on the optimal multiple paths between the OD pairs are corrected accordingly by comparing with the observed traffic volume. This comparison requires an additional assignment to be performed in each OD update cycle. The first assignment is used to calculate the traffic and the second is to update the OD traffic. Therefore, this method can produce more accurate results. Unlike the SPME method, the MPME method estimates the OD matrix according to the selection probability weights of multiple paths between OD pairs. That is, following Formula (16) instead of (13) is used.

$$\begin{aligned} T_{ij(\varphi)} &= \sum_r \left(T_{(E)ijr} \cdot p_{ijr} \right) \\ T_{(E)ijr} &= \frac{1}{N_{a\in(\tau,r)}} \cdot \left(\sum_{a\in(\tau,r)} T_{(E)ija} \right) \\ T_{(E)ija} &= \frac{V_a}{T_{a(N-1)}} \cdot T_{ij(\varphi-1)} \end{aligned} \tag{16}$$

Among these values, φ is the number of iterations, and p_{ijr} is the probability that path r is selected in traffic district i to j.

Since the MPME method can be used only in the (random) UE method, this paper uses the MPME method based on TransCAD software to accurately obtain the predicted value of common urban road network traffic.

4. **Case Study.** This paper selects a road network consisting of 62 nodes and 115 links. At the same time, this network diagram is divided into ten districts. The port freight OD matrix between ten districts is shown in Table 1. TransCAD software is used to achieve the assignment of road traffic and the OD matrix estimation. The collected data come from the peak time from 5 to 6 pm in the afternoon.

Table 1. OD freight information

District	1	2	3	4	5	6	7	8	9	10
O	582	691	739	871	1534	865	963	756	673	781
D	531	735	839	824	1464	753	1073	864	698	674

4.1. **Assignment of OD matrix.** The UE method was chosen to assign traffic flow using the Traffic Assignment function of TransCAD software, and the results are shown in Figure 1. As shown in Figure 1, the map is a closed network with a total of 115 roads, but only 38 have traffic flow based on statistics analysis; specifically the traffic at the edge of the network is zero and notably few (less than 10%) network edges have high-traffic flow. In other words, nearly all traffic volume is concentrated in the middle of the closed network, and most network edges have no traffic volume. This lack of traffic is clearly different from the actual urban road network. In real life, the vast majority of transportation network edge links are also connected to the external environment and there is a certain traffic volume. Therefore, it can be seen that the assignment of road traffic at the edge of the network may be distorted, affecting the accuracy of the results. For this reason, objective and accurate road traffic information is obtained through the estimation and superposition calculation of ordinary traffic flow.

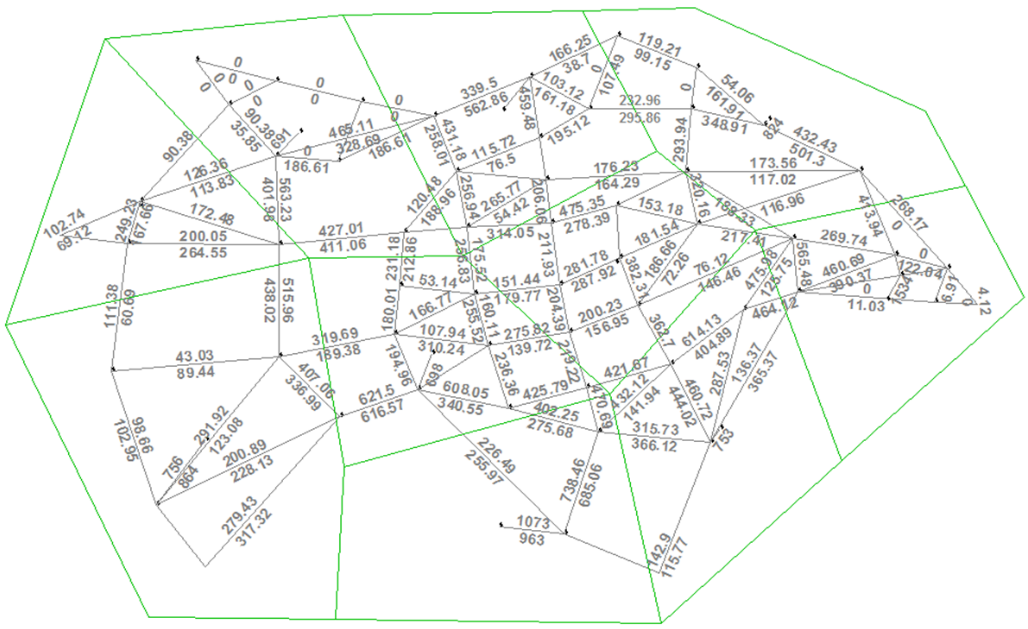

Figure 1. Results of traffic assignment

4.2. **OD estimated results and analysis of road flow superposition.** Using TransCAD software to realize the OD matrix estimation, the OD matrix and the traffic information for all 115 roads was obtained. Road information obtained from OD estimation is shown in Table 2.

Table 2. Results of OD estimation

Road	District	Road Capacity	Port Freight Volume	General Passenger Volume	Total Road Volume	Freight Volume Ratio	Congestion Level
98	4	5000	567	7488	8055	7.03	1.61
105	3	4000	528	3097	3625	14.57	0.90
93	3	4140	340	3035	3375	10.07	0.81
92	8	5040	370	4686	5056	7.31	1.00
87	8	4400	292	2895	3187	9.16	0.72
91	8	6000	612	7035	7647	8.00	1.27
94	8	4320	300	3576	3876	7.73	0.89
90	5	4320	459	3336	3795	12.09	0.87
50	5	4320	729	3241	3970	17.56	0.91
48	9	4320	897	4740	5637	15.91	1.30
49	9	4320	601	2176	2777	21.64	0.64
9	2	2340	126	2150	2276	5.53	0.97
18	6	2340	172	2060	2232	7.70	0.95

It can be understood from Table 2 as follows. (1) Traffic congestion occurred on some roads during peak time from 5 to 6 p.m., such as roads 98, 92, 91 and 48 whose congestion level index all exceed 1, because their general passenger volume is outstripping the road capacity. (2) The freight volume ratio of the above roads such as roads 98, 92 and 91 which are located in the non-adjacent port districts (4 and 8) is less than 10%. Therefore, in the non-adjacent port districts of the city, the impact of port freight on urban daily traffic is not very great. (3) However, near port districts (5 and 9) such as roads 90, 50, 48 and 49, port freight traffic accounts for a larger proportion of total road traffic, and the degree of road congestion is also high. It can be seen that port freight has affected urban daily traffic.

In this regard, this paper proposes corresponding solutions based on the analysis results that can not only choose to restrict the flow of port freight in the morning and evening traffic peaks, but also promulgate relevant policies and regulations so that the port freight traffic can avoid the links with serious congestion, such as roads 48 and 50. Because the former has got stuck in the enormous congestion, the latter may soon faces the serious congestion problem.

5. **Conclusions.** Taken into account is the influence of port container transportation on the traffic network around the city, on the one hand, we consider how to use OD estimation technology to derive all the network road traffic when the existing traffic information is incomplete. Conversely, we consider the supply-demand relationship between the port and the container logistics around the city to assign container traffic flows. Combining OD estimation with traffic flow assignment, the impact of port container traffic on road traffic around the city was evaluated through the superposition of traffic flow. The study's conclusions are outlined below. (1) When solving regional road traffic, in the case of known traffic exchanges between districts, traffic assignment methods can be used to infer traffic information for roads in different conditions. (2) Under the condition that the traffic of some links is known, the OD relationship between the districts can be solved through the OD matrix estimation method, and the traffic information of other unknown roads can be obtained through the assignment method. (3) In studying the influence of port container transport on the daily traffic around the city, a combination of traffic assignment

and OD matrix estimation can be employed to solve different types of road traffic through different means, and finally they are superimposed or compared with each other to achieve the purpose of analyzing and solving problems. In the near future, we plan to address the computational issue about dynamic characteristic of road flow.

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REFERENCES

[1] M. L. Hazelton, Some comments on origin-destination matrix estimation, *Transportation Research Part A: Policy and Practice*, vol.37, no.10, pp.811-822, 2003.
[2] M. L. Hazelton, Inference for origin-destination matrices: Estimation, prediction and reconstruction, *Transportation Research Part B: Methodological*, vol.35, no.7, pp.667-676, 2001.
[3] W. Ma and Z. S. Qian, Statistical inference of probabilistic origin-destination demand using day-to-day traffic data, *Transportation Research Part C: Emerging Technologies*, vol.88, pp.227-256, 2018.
[4] L. R. Foulds, H. A. D. do Nascimento, I. C. A. C. Calixto et al., A fuzzy set-based approach to origin-destination matrix estimation in urban traffic networks with imprecise data, *European Journal of Operational Research*, vol.231, no.1, pp.190-201, 2013.
[5] Z. Gao and B. Si, A new algorithm for estimation of origin-destination demands from link traffic flows, *Communication and Transportation Systems Engineering and Information*, vol.2, no.1, pp.30-41, 2002.
[6] R. R. García and R. D. Verastegui, A column generation algorithm for the estimation of origin-destination matrices in congested traffic networks, *European Journal of Operational Research*, vol.184, no.3, pp.860-878, 2008.
[7] R. R. García and Á. Marín, Simultaneous estimation of the origin-destination matrices and the parameters of a nested logit model in a combined network equilibrium model, *European Journal of Operational Research*, vol.197, no.1, pp.320-331, 2009.
[8] A. Tympakianaki, H. N. Koutsopoulos and E. Jenelius, c-SPSA: Cluster-wise simultaneous perturbation stochastic approximation algorithm and its application to dynamic origin-destination matrix estimation, *Transportation Research Part C: Emerging Technologies*, vol.55, pp.231-245, 2015.
[9] A. Tesselkin and V. Khabarov, Estimation of origin-destination matrices based on Markov chains, *Procedia Engineering*, vol.178, pp.107-116, 2017.
[10] L. Caggiani, M. Ottomanelli and D. Sassanelli, A fixed point approach to origin-destination matrices estimation using uncertain data and fuzzy programming on congested networks, *Transportation Research Part C: Emerging Technologies*, vol.28, pp.130-141, 2013.
[11] F. Parola and A. Sciomachen, Intermodal container flows in a port system network: Analysis of possible growths via simulation models, *International Journal of Production Economics*, vol.97, no.1, pp.75-88, 2005.
[12] D. Milevich, V. Melnikov, V. Karbovskii et al., Simulating an impact of road network improvements on the performance of transportation systems under critical load: Agent-based approach, *Procedia Computer Science*, vol.101, pp.253-261, 2016.
[13] X. H. Yang, Z. Cheng, G. Chen et al., The impact of a public bicycle-sharing system on urban public transport networks, *Transportation Research Part A: Policy and Practice*, vol.107, pp.246-256, 2018.
[14] J. K. Sankaran and L. Wood, The relative impact of consignee behaviour and road traffic congestion on distribution costs, *Transportation Research Part B: Methodological*, vol.41, no.9, pp.1033-1049, 2007.
[15] M. A. Figliozzi, The impacts of congestion on time-definitive urban freight distribution networks CO_2 emission levels: Results from a case study in Portland, Oregon, *Transportation Research Part C: Emerging Technologies*, vol.19, no.5, pp.766-778, 2011.