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THE STUDY ON GREENHOUSE GAS REDUCTION ACCORDING TO DELIVERY ROUTING PROBLEM OF CONSUMER ELECTRONICS

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Abstract. *Greenhouse gas reduction has become a major priority for advanced nations since the Kyoto Protocol of 1997. Republic of Korea declared to target low carbon eco-friendly development as the national vision in 2008 and has made crucial attempts to achieve the national goal of 37% less greenhouse gas emission by 2030 in comparison with BAU. The amount of greenhouse gas emitted from road transportation covers 95% of the overall transportation sector in Korea. Therefore, delivery logistics of consumer electronics is of much importance in the reduction of greenhouse gas. This study looks into the effort to reduce greenhouse gas by establishing specific information of delivery frequency and route decisions (VRP, PRP) needed for the delivery and installation of consumer electronics in urban and rural regions.*
Keywords: Greenhouse gas emission, Vehicle routing problem, Pollution routing problem

1. **Introduction.** Greenhouse gas reduction has become a major priority in advanced nations in accordance with the 1992 United Nations Framework Convention on Climate Change (UNFCCC) and 1997 Kyoto Protocol regulations. Proceedings at the 2011 Durban Conference (COP 21) held in South Africa, which was attended by all nations in cooperation to change the Kyoto protocol, led to the decision to finalize all negotiations for new climate regime (Post 2020) by 2015 and its mainstream launch by 2020. This marked the beginning of a new phase in global climate change.

In 2008, Republic of Korea declared to target low carbon eco-friendly development as the national vision and attempted to achieve the national greenhouse gas reduction goal established by the roadmap acquired in 2014. We are striving to reduce greenhouse gas emissions, as well as the voluntary reduction target submitted (INDC, intended nationally determined contributions), down to 37% by 2030 in comparison with BAU (business as usual).

Domestic consumer electronics' sales status and prospects are as shown on Table 1. Large appliances are prospected to grow from 3,690 to 3,860 million dollars between 2012 and 2015, while small appliances are predicted to increase from 2,850 to 3,360 million dollars from 2013 to 2015 [1].

Recently, Internet shopping malls have been seeking to improve both delivery and installation services due to the rising online demands of consumer electronics from customers. High demand of online delivery orders requires various studies to identify the logistics cost as well as its effect on greenhouse gas emission from frequent delivery. However, current researches regarding delivery logistics only aim to minimize logistics cost and time (2014) [2]. This in turn is experimented with specific algorithms to calculate methods for reducing delivery time and cost by changing delivery route options. In addition, other

TABLE 1. Domestic consumer electronics' sales status and prospects

(Unit: $100 million)

Category	2012	2013	2014	2015
Large Appliance	36.9	37.8	38.2	38.6
Small Appliance	28.5	30.2	31.9	33.6

than current researches, which reduce carbon emission by shortening a vehicle's idle time (2011), there are no other viable studies to reduce greenhouse gas emission [3].

This study looks into greenhouse gas emission reduction plans by establishing specific delivery methods, which are composed of delivery route and frequency, needed for the delivery and installation of consumer electronics in urban and rural regions. The amount of greenhouse gas from road transportation is estimated to be 95.01% of the total emission from the transportation sector. Therefore, the results of this study to reduce any or all greenhouse gas emission from road transportation is very important [4].

In Chapter 2, the scope and data used in this research are defined. Actual experimental computations are compared in Chapter 3, and conclusions are addressed in Chapter 4.

2. Scope and Data of Research.

2.1. **Target of the study.** This research was carried out based on actual cases from a domestic Company 'K' during its delivery of consumer electronics. Currently, on a day-to-day basis, Company 'K' is using two 2.5ton transportation vehicles for delivery and installation of large appliances as well as two extra 2.5ton transportation vehicles designated only for the delivery of small and medium-sized appliances. This causes for each vehicle to travel to their routes even though the truck is not fully loaded. Therefore, the frequency of delivery transportation will generate more greenhouse gas emission.

In this study, we are looking to change the current delivery method due to the problems regarding vehicle load factor and the immense amount of greenhouse gas emitted. First off, change the number of 2.5ton transportation vehicles assigned for the delivery of small and medium appliances from 2 to 1 as well as establish a different delivery frequency and route in order to conduct a comparison study. The first plan is to maintain the current day-to-day delivery frequency and apply the pollution routing problem (PRP) as the delivery route determining method. The second plan is to consider an every-other-day delivery frequency and apply the vehicle routing problem (VRP) route method. The third plan is to administer the every-other-day delivery frequency and PRP together.

In order to test emission levels of greenhouse gas in varying settings and factors based on both delivery frequency as well as route determining method, the scope of this study consists of specifically selected areas of urban and rural regions (Figure 1). Dongdaemun-gu of Seoul was selected as the main urban region because it has the most frequent delivery cases due to the high population density. However, the distance between delivery locations was in close proximity. On the other hand, Dangjin city of Chungcheongnam-do, the main rural region, has the lowest delivery frequency cases due to the low population density while the proximity of delivery locations are further apart in comparison. The actual data from Company 'K' regarding daily deliveries for 30 days of large, medium and small consumer electronics are shown as below (Table 2).

Distance calculation between each delivery location is applied using the rectilinear distance equation for proven affinity of the actual distance referenced in Kim et al. (2011) [5].

$$
\begin{aligned}
&Rectilinear\ distance\ (km)\\
&= \begin{pmatrix} |latitude\ of\ origin - latitude\ of\ destination| \times 110996.8 \\ +|longitude\ of\ origin - longitude\ of\ destination| \times 87754.2 \end{pmatrix} \div 1000
\end{aligned}
$$

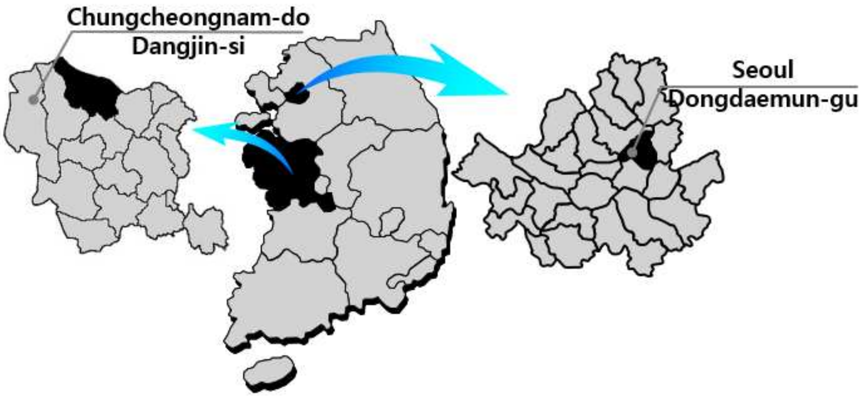

Figure 1. Research environment (main urban and rural regions)

Table 2. Regional delivery cases

Region	Research Environment	Average Daily Delivery Cases	Std. Dev.
Urban	Dongdaemun-gu, Seoul	100	10
Rural	Dangjin, Chungcheongnam-do	40	5

2.2. **Mathematical model.** VRP is a method that can be used for finding the shortest distance determining research from using more than one vehicle to visit more than one depot (1959) [6]. However, in comparison, VRP can consider more options than TSP (traveling salesman problem). Therefore, time consumption can lead to the inability to find the optimal solution (2013) [7]. However, according to Lin et al. (2014), it was found that if heuristic algorithms are applied to the actual constraint conditions considering cost and time factors, troubleshooting time for optimal solution can be reduced [8]. According to Kara et al. (2008), it is described that PRP is more complex than VRP because it considers a combination of economic and environmental factors [9].

Therefore, this study derives PRP results using genetic algorithms and then analyzes its comparison to VRP values. The variables and models applied within the optimal PRP model, as proposed in Kara et al. (2008), are shown below [9].

Parameters

d_{ij}	Distance from node i to node j
q_i	Nonnegative weight of node i
m	Number of identical vehicles
Q_0	Initial value of flow from the origin to the first node of the tour in the case of collection
M	The flow capacity of the arcs of the network
x_{ij}	$\begin{cases} 1, \text{the tour of a vehicle} \\ 0, \text{otherwise} \end{cases}$
y_{ij}	$\begin{cases} 1, \text{the flow on the arc } (i,j) \\ 0, \text{otherwise} \end{cases}$

Objective Function

$$\min \sum_{i=0}^{n} \sum_{j=0}^{n} d_{ij} y_{ij} \tag{1}$$

$$\sum_{i=1}^{n} x_{0i} = m \tag{2}$$

$$\sum_{i=1}^{n} x_{i0} = m \tag{3}$$

$$\sum_{i=0}^{n} x_{ij} = 1 \tag{4}$$

$$\sum_{j=0}^{n} x_{ij} = 1 \tag{5}$$

$$\sum_{\substack{j=0 \\ j\neq i}}^{n} y_{ij} - \sum_{\substack{j=0 \\ j\neq i}}^{n} y_{ij} = q_i,\ i = 1, 2, \ldots, n \tag{6}$$

$$y_{0i} = Q_0 x_{0i},\ i = 1, 2, \ldots, n \tag{7}$$

$$y_{ij} \leq (M - q_i) x_{ij},\ (i, j) \in A \tag{8}$$

$$y_{ij} \geq (Q_0 + q_i) x_{ij},\ \forall (i, j) \in A \tag{9}$$

$$x_{ij} = 0 \text{ or } 1,\ (i, j) \in A \tag{10}$$

Equation (1) represents the objective function, and Constraints (2) and (3) represent m number of vehicles used. Constraints (4) and (5) are restrictions of single visitations to each node. (6) represents a constraint preventing sub tour, and (7) is a constraint for initializing the cost of the first generated node. (8) prevents overloading of a vehicle and (9) represents the lower limits of the transportation route. Equation (10) is defined as completeness.

2.3. **CO_2 emission model.** This study performed PRP by considering the loading capacity, speed, and slope of the road as environmental factors. The MEET (methodology for calculation of transportation emissions and energy consumption) equation, proposed by Hickman et al. (1999), calculates the consumption of energy produced [10]. The equation and formula are shown below.

$$F = Emission \times GC \times LC \times D \tag{11}$$

$$Emission = 0.0617v^2 - 7.8227v + 429.51 \tag{12}$$

$$GC = A_6 v^6 + A_5 v^5 + A_4 v^4 + A_3 v^3 + A_2 v^2 + A_1 v + A_0 \tag{13}$$

$$LC = k + n\gamma + p\gamma^2 + q\gamma^3 + r/v + s/v^2 + t/v^3 + u/v \tag{14}$$

F	CO_2 Emission
D	Distance
v	Vehicle speed
γ	Gradient
$k, n \sim u$	Coefficient
$A_0 \sim A_6$	Coefficient

Equation (11) represents the emission amount of greenhouse gas and (12) represents the amount of greenhouse gas emitted based on speed. Formula (13) is the gradient correction from the slope of the road and (14) represents the load correction of the loading capacity.

3. **Computational Experiments.** Three different delivery methods, which can change the combination outcome between vehicle delivery frequency and route determining method, were summarized using the results from distance traveled and the amount of greenhouse gas emitted and then compared with current delivery method results.

TABLE 3. Result comparison between AS_IS and TO_BEs

Calculation Method	Urban region Seoul Dongdaemun-gu		Rural region Chungcheongnam-do Dangjin-si	
	Distance (km)	Greenhouse Gas Emission ($kgCO_2$)	Distance (km)	Greenhouse Gas Emission ($kgCO_2$)
AS_IS (day-to-day / VRP)	615.52	151.35	1365.35	458.25
TO_BE 1 (day-to-day / PRP)	679.25	136.57	1487.17	438.25
TO_BE 2 (every-other-day / VRP)	429.57	98.14	784.36	417.25
TO_BE 3 (every-other-day / PRP)	547.19	95.21	901.47	398.97

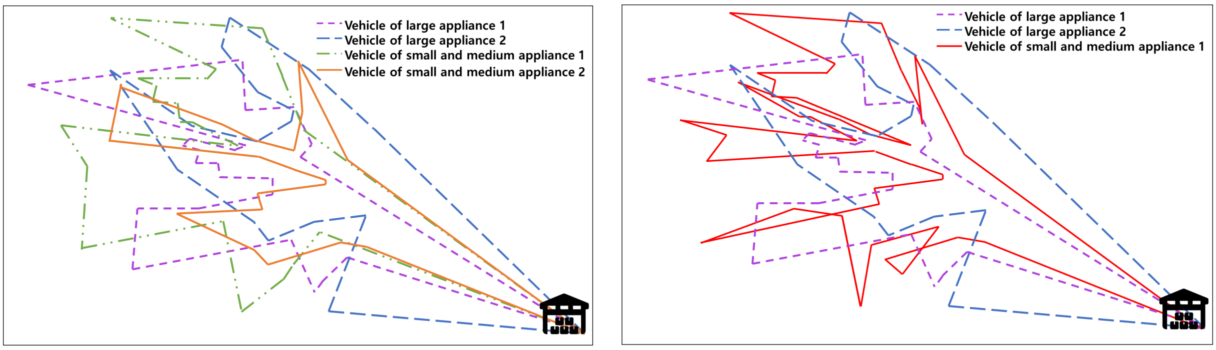

FIGURE 2. The best vehicle route of TO_BE 3 in comparison to AS_IS (Dangjin, Chungcheongnam-do, Day 17th)

When TO_BE 1 was chosen with PRP, the distance was increased while greenhouse gas emission was reduced. Every-other-day delivery frequency with TO_BE 2 resulted in a reduction in both distance traveled and emitted greenhouse gas. TO_BE 3 showed the most reduction in greenhouse gas emission in comparison to all other cases (Table 3).

4. Conclusions.

This study was conducted using actual data from Company 'K', a domestic consumer electronics company, to determine a strong correlation between greenhouse gas emission and distance traveled by delivery vehicles when the frequency of delivery and delivery route were changed within urban and rural regions (Table 3).

In conclusion, when comparing the application of PRP (TO_BE 1), every-other-day delivery (TO_BE 2), and a combination of every-other-day delivery and PRP (TO_BE 3) to the current delivery method (AS_IS), all plans showed reduction in greenhouse gas emission levels. Additionally, however, greenhouse gas reduction levels were greater in urban region than rural area.

This study assumed there were no delivery time restrictions. However, future studies should be carried out with a specific time limit for particular delivery logistics. This will allow for a more realistic approach to identifying further reduction in greenhouse gas emission levels as well as logistics fees while delivering consumer electronics to consumers.

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