Multi-Agent Modeling for Evaluating Urban Freight Policy Measures on Urban Distribution Centre

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This paper discusses a multi-agent systems (MAS) model in the context of evaluating city logistics measures. The purposes of the freight policy measures are to change the stakeholders' delivery behaviour and reduce the negative environmental impacts when they are encouraged to take part in the joint delivery system with the help of the urban distribution centre utilities. The MAS model includes the vehicle routing and scheduling problem with soft time window (VRPSTW) applied by the freight carriers and neutral carrier and is simulated with dynamic delivery demands and time window of the residents and shop owners. The preliminary results of the model show that the joint delivery system has the potential to reduce the total distance travelled, operation costs, and truck emissions and to increase loading factor.

Key Words : *multi-agent systems, urban distribution centre, joint delivery systems, city logistics*

1. INTRODUCTION

Recently, the population in megacities continues to grow especially in developed countries such as Tokyo, New York, Delhi and Paris. They have development systems for habitation, sanitation, transportation and various utilities. The high density of population and utilities considerably facilitate businesses as relatively large amount of GDP are found to be produced inside highly urbanized areas (OECD, 2007). These have caused tremendous demand in delivery services and freight traffic on top of the existing passenger transport, which have caused traffic congestion, traffic accidents, illegal parking (loading/unloading on street sides) and affected environmental issues without the proper implementation of freight policy measures (Duin, 2012). Consequently, this paper aims to focus on delivery businesses in the urban area. Over the years, urban freight logistics have become serious problems in city planning, which has been considered in city logistics as defined as

"the process for totally optimizing the logistics and transport activities by private companies in urban areas while considering the traffic environment, traffic congestion and energy consumption within the framework of market economy" (Taniguchi, 1999).

Urban freight logistics systems are critical to a delivery business. The transportation system is the essence of the logistics that affect the product costs, customer satisfaction by just in time delivery with effective and efficient vehicle routing and scheduling. One solution to improve and reduce the urban freight logistics problems is to introduce urban distribution centres (UDCs) (Dablanc, 2007). The UDC is a promising concept, where the loads of delivery trucks from different carriers are transferred and consolidated to new trucks to increase the load factor and to allow for easier time-windowed operation to avoid traffic congestion (Quak, 2009). A higher load factor in the city is also found to minimize harmful effects associated with city logistics (Duin, 2012). Previously, several researches have shown the successful utilization of urban distribution centre (Marcucci, 2008). However, in contrast to reality, the concept has failed in some cases as freight carriers are under intense pressure from strong market competition and the requirement from customers to provide Just-In-Time (JIT) delivery system (Germain, 1996). These differences between results from evaluation models and actual implementation of UDCs might be due to the fact that most models used did not consider multiple stakeholders' objectives.

Hence, there is a desire to find out if the concept of the UDC and the joint delivery systems has real values in enhancing city logistics when more stakeholders' objectives are considered in the MAS model.

2. OBJECTIVES

The objective of this paper is to study the effect of city logistics measures by implementing the joint delivery systems, an urban distribution centre, and time window restriction. To study the behaviour of urban freight stakeholders and their interaction, which is affected by the policy measures, the multi-agent systems (MAS) modelling approach is a useful methodology to represent their multi-objective nature. This paper discusses the MAS in the context of city logistics measures that are aimed at changing the stakeholders' behaviour and reducing the environment impacts.

3. MULTI-AGENT MODEL FRAMEWORK

(1) Multi-agent system (MAS)

MAS is a system composed of multiple interacting intelligent agents. MAS can be used to solve problems that are difficult or impossible for an individual agent or a monolithic system to solve. Intelligence may include some methodic, functional, procedural or algorithmic search, acquisition and processing approach. Moreover, MAS is a useful methodology to examine the multi-objective nature of an urban logistics system and study the behaviour of the stakeholders, who are affected by the freight policy measures. MAS consist of an environment with multiple autonomous agents with the ability to distinguish, perceive and take action while incorporating the interactions of other agents (Teo, 2012). Additional information in MAS can be found in related sources (Weiss, 1999 and Wooldridge, 2009).

This paper proposes to use MAS modelling approach to evaluate the utilization of the joint delivery system and urban distribution centre.

(2) VRPTW

VRPTW model plans and implements delivery routing and schedules of trucks for each freight carrier. This paper includes the study of delivery and pickup activities from the shop owners at shopping street, which use the pickup and delivery vehicle routing problem with time windows (PD-VRPTW) model by planning and implementing delivery routing and schedules of trucks for neutral carrier (UDC truck operation). Likewise, this paper seeks to follow and modify the MAS model framework for vehicle routing and scheduling problem with time window forecast (VRPTW-F) (Tamagawa, 2010) and pickup and delivery vehicle routing problem with time windows (PD-VRPTW) as shown in Fig.1.

To determine the optimal solution by minimizing the total transport cost of freight carriers and neutral carrier, this research had applied the vehicle routing and scheduling problem with soft time windows (VRPSTW) model by Qureshi (2008) to study the pickup and delivery goods activities.

The model can be formulated as follows:

$$\min \sum_{k\in K} \sum_{(i,j)\in A} c'_{ij} x_{ijk} \qquad (1)$$

subject to

$$\sum_{k\in K} \sum_{j\in V} x_{ijk} = 1 \qquad \forall i \in C \qquad (2)$$

$$\sum_{i\in C} d_i \sum_{j\in V} x_{ijk} \le q \qquad \forall k \in K \qquad (3)$$

$$\sum_{j\in V} x_{0jk} = 1 \qquad \forall k \in K \qquad (4)$$

$$\sum_{i\in V} x_{ihk} - \sum_{j\in V} x_{hjk} = 0 \qquad \forall h \in C, \qquad \forall k \in K \qquad (5)$$

$$\sum_{i\in V} x_{i0k} = 1 \qquad \forall k \in K \qquad (6)$$

$$a'_i \le s'_{ik} \le b'_i \qquad \forall i \in V, \qquad \forall k \in K \qquad (7)$$

$$a_i \le s_{ik} \le b'_i \qquad \forall i \in V, \qquad \forall k \in K \qquad (8)$$

$$s_{ik} + t_{ij} - s_{jk} \le (1 - x_{ijk}) M_{ijk}$$
$$\forall (i,j) \in A, \qquad \forall k \in K \qquad (9)$$

$$x_{ijk} \in \{0,1\} \qquad (i,j) \in A, \qquad \forall k \in K \qquad (10)$$

The two decision variables in the VRPSTW are the service start time, s_{jk}' of truck $k \in K$ at vertex $j \in C$, that will determine the arrival time at vertex $j \in C$ and travel cost of arc (i, j), and x_{ijk}, where $x_{ijk} = 0$ when arc (i, j) is used and $x_{ijk} = 1$ when arc (i, j) is not used in the solution. The objective function (Eq. (1)) minimizes the sum of delivery costs that consist of the fixed vehicle utilization cost, travel cost on arcs and the penalty costs. Constraint (2) ensures that each customer is serviced only once and constraint (3) makes sure that the load carried by the vehicle is within the limit of the vehicle's capacity. Constraints (4) and (6) determine that the vehicle shall start and end at the depot while constraint (5) ensures that the vehicle entering vector h must also leave from vector h. Constraint (7) restricts the arrival time to be within the relaxed time window of a_i' and b_i' and constraint (8) ensures that the service start time is within a_i and b_i'. Constraint (9) shows that if a vehicle travels from i to j, the service at vector j can only start after service at vector i is completed. The last constraint, (10) is the integrality constraint, which completes the model formulation.

The problem described here is a NP-hard (Non-deterministic Polynomial-hard) combinatorial optimization problem. Thus, some heuristic algorithms are used to provide good and fast solutions for MAS model. The model described here uses Insertion Heuristics to solve the VRPSTW.

(2) Q-learning theory

Q-learning is a reinforcement learning technique that works by learning an action-value function that gives the expected utility of taking a given action in a given state and following a fixed policy thereafter. One of the strengths of Q-learning is that it is able to compare the expected utility of the available actions without requiring a model of the environment. A recent variation called delayed Q-learning has shown significant improvements, bringing probably approximately correct learning (PAC) bounds to Markov decision processes (Alexander, 2006). A typical learning algorithm for the administrator can be represented by Eq. (11).

$$Q(s_t, a_t) \leftarrow (1-\alpha)Q(s_t, a_t) + \alpha\left[r_{s_t,a_t} + \gamma \min Q(s_{t+1}, a_{t+1})\right] \quad \text{-----(11)}$$

where ,

$Q(s_t, a_t)$: expected truck emission level in state *t* due to action in state *t*.

$Q(s_{t+1}, a_{t+1})$: expected truck emission level in state *t+1* of all actions

γ : discount rate for administrator ($0 < \gamma < 1$)

α : learning rate for administrator ($0 < \alpha < 1$)

r_{s_t,a_t} : immediate truck emission level in state *t* due to action in state *t*.

The learning rate of 1 represents the administrator, who will consider the most current information while 0 means the administrator does not learn. Discount rate set at 1 means that the administrator will consider the long term reward while 0 means that the administrator concerns only on the current rewards. The oxides of nitrogen (NO_x) emission is estimated using Eq. (12) (NILIM, 2003) assuming delivery truck vehicles use diesel fuel.

$$NO_x = l_{ij}\left(1.06116 + 0.000216v_{ij}^2 - 0.0246v_{ij} + \frac{16.258}{v_{ij}}\right) \quad \text{-----(12)}$$

where,

NO_x : expected nitrogen oxide emission in grams

l_{ij} : length of road link between nodes *i* and *j* in kilometres

v_{ij} : speed of vehicle travelling on road link between nodes *i* and *j*

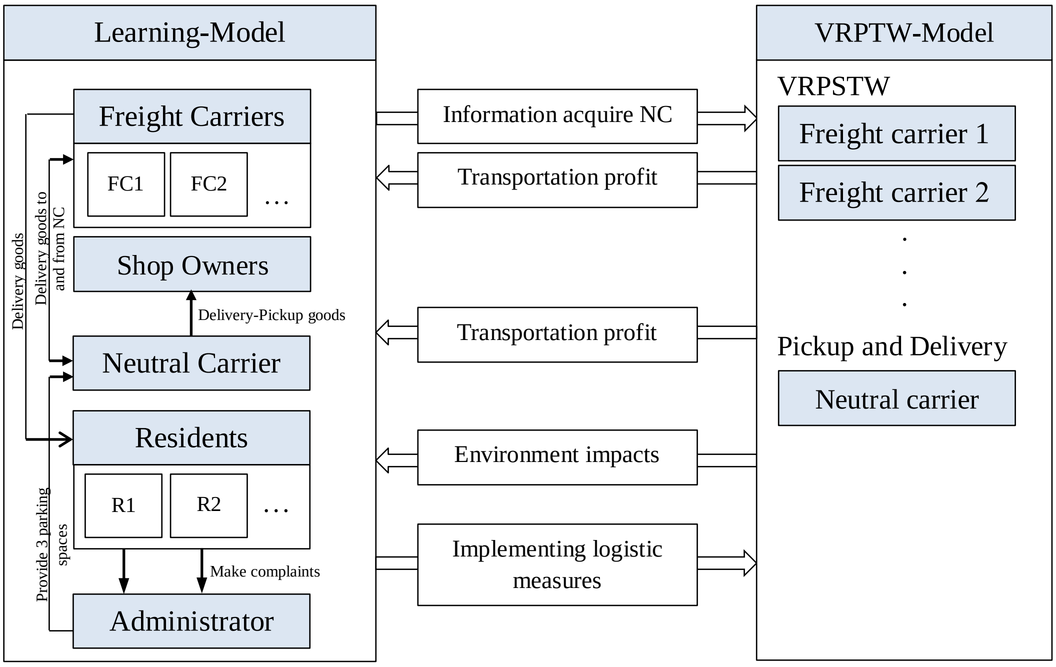

Fig.1: New MAS model framework with vehicle routing and scheduling problem with time window

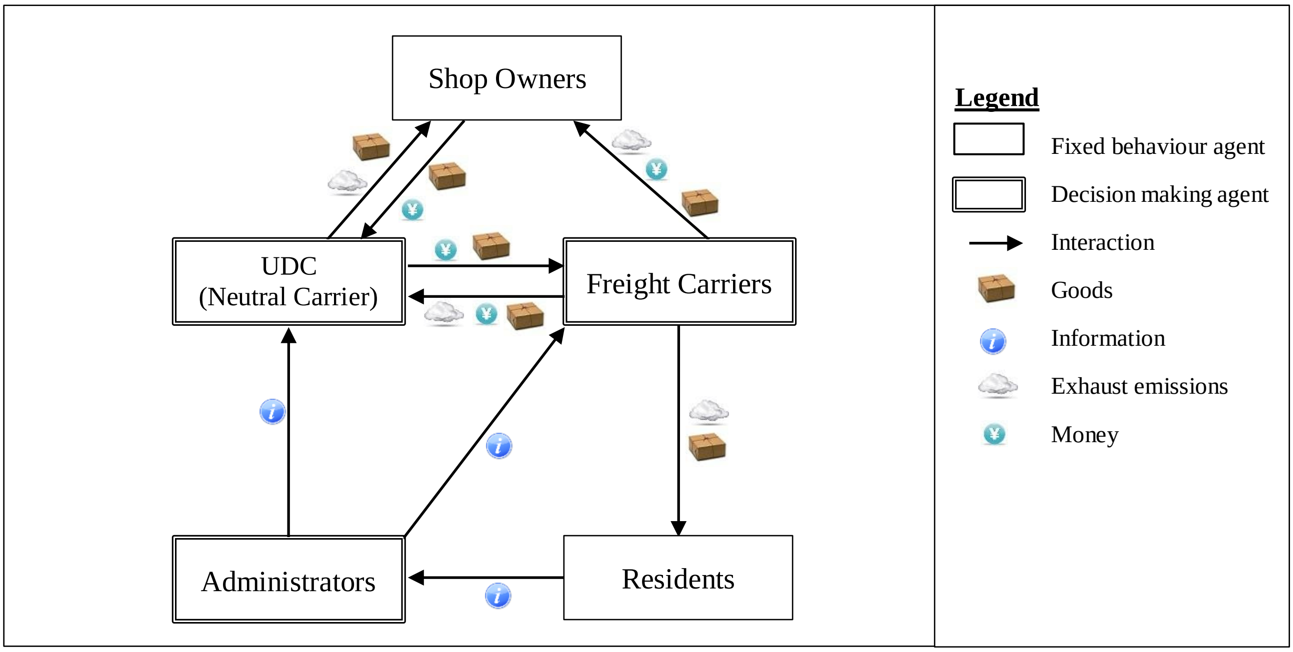

Fig.2: Stakeholder interaction order

(3) Stakeholders associated with urban freight transport

In a multi-agent model, stakeholders have their own objectives as follows;

Freight Carriers

Objective: Minimize operation cost and maximize benefit (eg. Less truck used etc.)

⬇

Behaviour: Propose the fee for transporting goods to shop owners and residents without delay.

Shop Owners

Objective: Minimize delivery cost.

⬇

Behaviour: To participate or withdraw from the joint delivery system.

Residents

Objective: Minimize the NO_x emissions by trucks.

⬇

Behaviour: Complain to administrator when NO_x emissions in their area exceed the environmental limit.

Administrator

Objective: Minimize the number of areas where residents complain about NO_x emissions.

⬇

Behaviour: Encourage freight carriers and shop owners to use UDC with subsidies.

Neutral carriers

Objective: Maximize the profit of delivery goods.

⬇

Behaviour: Propose the fee for transporting goods to shop owners without delay.

4. EXPERIMENT SETUP

The hypothetical test road network is shown in Fig.3. Four freight carriers are named as carriers A, B, C and D and are located at nodes 2, 11, 15 and 22 respectively. Nodes 9, 14 and 19 are the locations of shop owners whilst the rest of the nodes represent the residents. The MAS model is iterated for 360 days, which is equivalent to a year. The experiment of without/ with the UDC operations are as following;

Without UDC case

(Step 1) Freight carriers deliver goods to residents.

(Step 2) Freight carriers go to the shop owners to

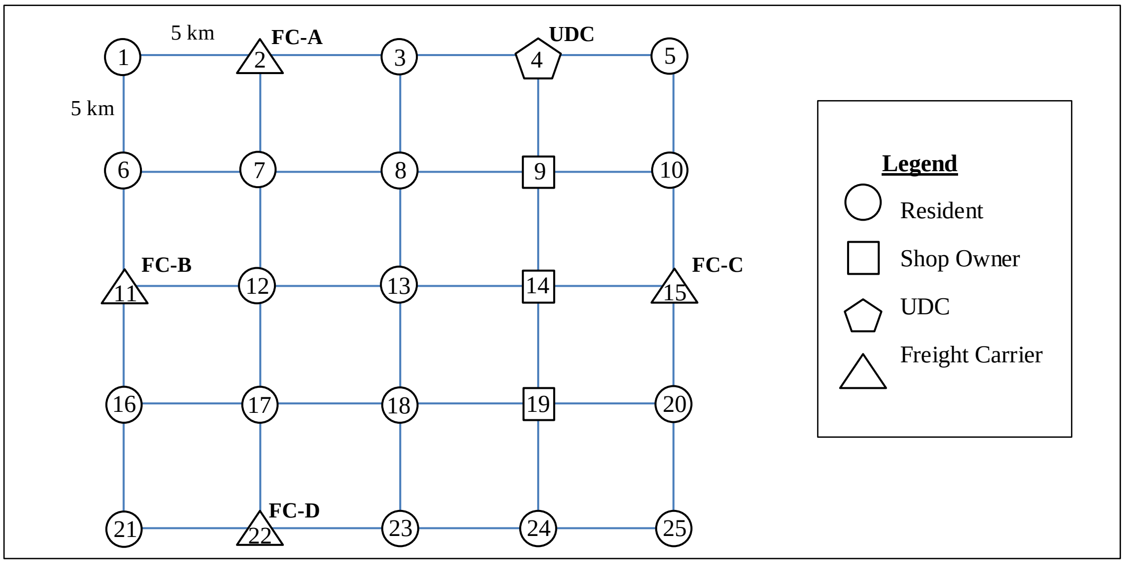

Fig.3: Test road network

pick up goods that are required to be delivered to residents in the next step.

(Step 3) Repeat step 1 with the amount of pickup goods in step 2 for the next day.

With UDC case

(Step 1) All freight carriers deliver goods to the UDC.

(Step 2) Divide the distribution activity into two scenarios. Firstly, the neutral carrier delivers and pickups goods to/from shop owners. Secondly, other trucks from neutral carrier deliver goods to the residents, which included the picked up goods from shop owners.

(Step 3) Repeat step 1 and 2 for the next day.

This initial experiment was done for the base case where no learning has taken place within the MAS model.

5. RESULT AND DISCUSSION

The impact of truck emissions from the hypothetical test road network was estimated using Eq. (12) and the oxides of nitrogen (NO_x) emission are shown in Fig. 4.

Fig. 4 shows the reduction of the oxides of nitrogen due to the UDC utilization. In this research, the distribution activities are divided into three scenarios to evaluate the benefit of entire distribution activities:

Scenario 1: The delivery activity serviced by carriers to residents.

Scenario 2: The pickup/ delivery activities by carriers from/to shop owners.

Scenario 3: The combination of scenario 1 and 2.

It was found that the UDC usage reduced the distance travelled, which will otherwise be greater if each carrier was to deliver the goods separately. Air pollutants have also decreased with the reduced distance travelled. The use of UDC reduced the NO_x effects by almost 53 percent for resident delivery activity (scenario 1) and 54 percent for shop owner delivery activity (scenario 2). In addition, the benefit NOx for entire system decreased 54 percent (scenario 3).

Table 1: Modelling assumptions

Modelling assumption
General assumption
Service time for delivery is from 8 AM. until 8 PM.
There is only one type of truck.
There is only one type of goods.
The dynamically assigned quantities of delivery and pickup goods are fixed throughout the year.
The dynamically assigned time window of delivery and pickup goods is fixed throughout the year.
Model illustrates a hypothetical city.
UDC
Access to the UDC is closed to the freight carriers.
The UDC can have an early delivery, fixed time deliveries or full truck delivery scheme.
UDC usage charge is 150 yen/parcel.
Freight carriers and neutral carrier trucks
Vehicular costs are fixed.
Truck capacity is 130 parcels.
Service time window ranges between 15 to 35 minutes
Freight carriers travel with an average velocity at 30 kph.
Penalty charge for early delivery is 1 yen/minute.
Penalty charge for delay delivery is 5 yen/minute.

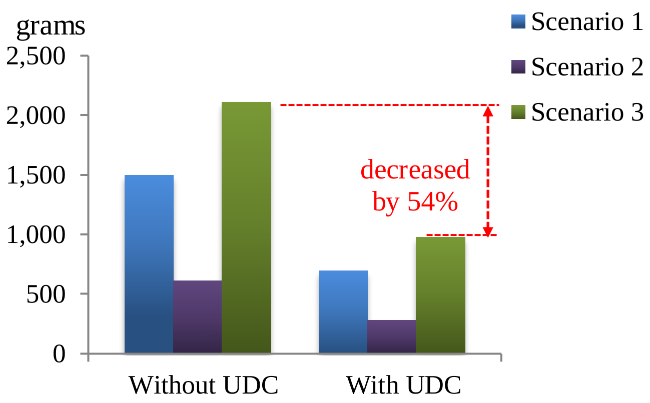

Fig.4: NOx emission level of implementing UDC comparison

Table 2 The performance of UDC Benefits

Urban Distribution Usage	**Distribution Activities**	**Truck (veh)**	**Cost (yen)**	**Average Distance Travelled (km)**	**Load Factor (%)**
Without	Scenario 1	14	484,997	1,497.14	58.42%
	Scenario 2	9	250,966	613.06	31.47%
	Scenario 3	23	735,963	2,110.20	47.88%
With	Scenario 1	11	297,375	693.42	74.35%
	Scenario 2	3	180,713	281.08	94.42%
	Scenario 3	14	478,088	974.50	78.65%
Benefit Comparison	Scenario 1	-21.43%	-38.69%	-68.45%	+27.27%
	Scenario 2	-66.67%	-27.99%	-90.21%	+200.00%
	Scenario 3	-39.13%	-35.04%	-74.77%	+64.29%

Table 2 shows the number of trucks, delivery cost, total distance travelled and load factor for one year. The results show similar trend of reducing the number of trucks by 40 percent, total cost by 35 percent and total distance travelled by 75 percent when UDC was used. In addition, the truck load factor increased by 36 percent with the presence of UDC. Moreover, the total benefit comparison of all distribution activities show that the UDC is numerous beneficial. These results show the potential of UDC as a possible city logistic policy measure.

The behaviour changing of stakeholders with the various service charge of the UDC were evaluated using Eq. (11) and comparisons of the benefits of UDC usage are shown in Fig. 5 to Fig. 7. In this research, the service charges of the UDC are set in four categories which free of charge, 100 yen, 150 yen and 200 yen charge.

Fig. 5 shown the trend of UDC frequency usage is declined when the service charge increasing. The freight carriers are intended to deliver the goods directly to their customers.

The cost comparison of UDC usage is shown in Fig. 6. The UDC can reduced the delivery costs with free of charge, in contrast, if the UDC charge some service fee, freight carriers avoid to use the UDC because their delivering costs is higher. Similarly, the trend of NOx emission is going up due to the UDC service charge because of the delivery cost is high therefore, freight carriers prefer to delivery by themselves. However, the using of UDC with free of charge can reduce the NOx emission, the trend of NOx emission as shown in Fig. 7.

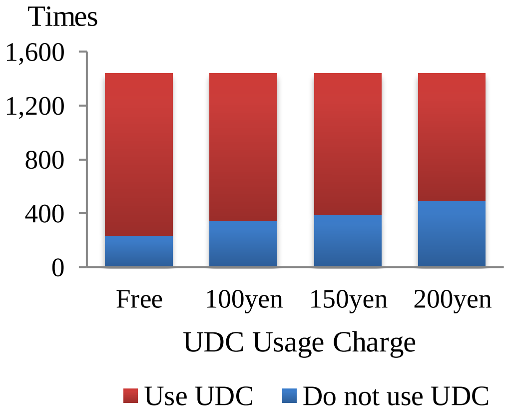

Fig.5: Frequency of UDC usage

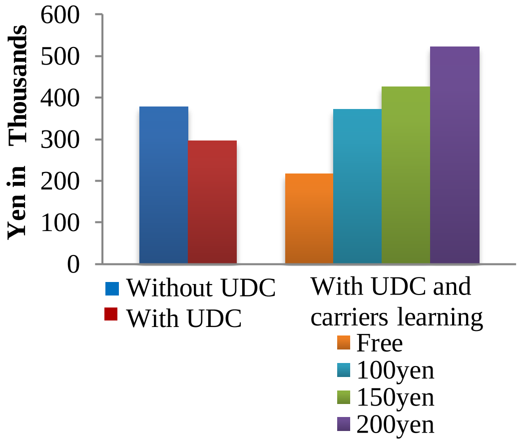

Fig.6: Cost comparison of UDC usage

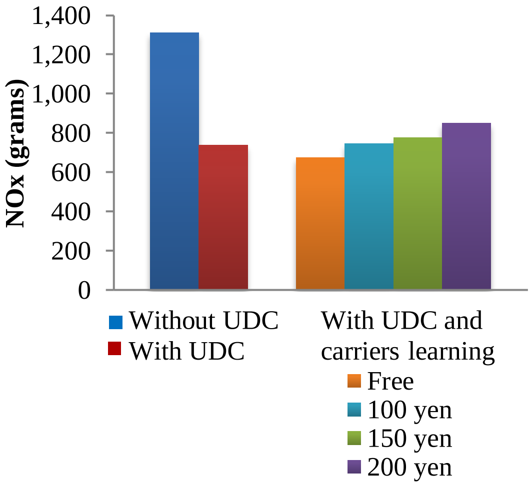

Fig.7: NOx emission comparison of UDC usage

6. CONCLUSION

The initial findings of operating cost reduction and minimized environmental impact for implementing UDC are encouraging and more work will be done to include additional schemes to evaluate the effectiveness of the UDC. The urban freight emission reduction is achieved from the reduction in distance travelled resulting from the replacement of individual delivery to consolidated delivery with the presence of a UDC. The effect of distance and emission reduction is, therefore, dependent on the number of carriers who used the UDC. The UDC is not more beneficial by the increasing the service charge.

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