MULTI-AGENT MODELLING SYSTEMS FOR EVALUATING URBAN FREIGHT POLICY MEASURES ON PARKING SPACE RESTRICTION

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ABSTRACT

This paper presents the Multi-Agent System (MAS) model for evaluating the City Logistics measures like the joint delivery systems and parking space restriction. This research is directed at evaluating possible measures that will provide logistics efficiency in the city faced with congested urban traffic conditions. The focus of the study is on the interaction and cooperation between urban freight stakeholders when City Logistics measures are implemented and to investigate the behaviour of stakeholders with their objectives. The preliminary results of the model show that the joint delivery system and parking space restriction have the potential for improving the environmental issues. In addition, the parking restriction by the government can increase the frequency of UDC usage.

Keywords: multi-agent system, city logistics, parking restriction, reinforcement learning, joint delivery system

INTRODUCTION

Preceding researches in City logistics have attempted to model and provide solutions to businesses and the community by ensuring optimum efficiency of goods delivery, reliability and customer service while reducing the negative environmental issues, for example, air pollution emissions, energy consumption and traffic congestion. 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 consolidated at a single facility and transferred to new trucks to increase the load factor and to allow for easier time-windowed operation to avoid traffic congestion (Quak, 2009). The main factors contributing to a successful implementation of an UDC are its location in/ near the city, subsidy collection, service cost of the UDC, shorter delay in delivery time and the collaborative relationship between the shippers and freight carriers. Furthermore, it is found that the most challenging factor is the collaboration between all involved stakeholders within the complex operation (Duin et al., 2012). On top of this, another associated city logistics problem is the illegally parked vehicles that are rampant in urban areas for the purpose of loading/ unloading activities. With limited parking spaces, many vehicles park illegally beside the road, which lead to traffic safety problems and deterioration of environmental issues.

The Motomachi shopping street located in Yokohama, Japan, was chosen as the case study for this research. To recognize the interaction between logistics stakeholders with their objectives, we examine results from customer demands, delivery schedule and time window at Motomachi shopping street in Yokohama, Japan. A joint delivery system was established along this shopping street, which encompassed the freight carriers, a neutral carrier, shop owners, residents, administrators and shopping street association. Besides, the administrator provided 3 parking spaces only for the neutral carrier. Consequently, this paper aims to study the benefit of the UDC with supporting city logistics measure.

Several researches have studied on urban freight logistics by using the MAS modelling approach to evaluate city logistics measures, for instance, road pricing, toll pricing, truck ban, time windows restrictions, load factor control, operation subsidies and urban distribution centre usage (Antal, 2010; Duin et al., 2012; Vita and Janis, 2005; Teo et al.; 2012, Tamagawa et al., 2010; Taniguchi et al., 2007). However, the interaction among the stakeholders of the joint delivery system and the consideration of illegally parked vehicles are intended to be studied in this research. The aim of this research is to explore if the implementation of joint delivery system and parking space restriction as the city logistics measures can lead to an overall system benefit for all stakeholders by using the MAS model with reinforcement learning.

OBJECTIVE

The objective of this paper is to study the effect of city logistics measures consisting of the joint delivery systems, an urban distribution centre, and parking space restriction. To study the behaviour of urban freight stakeholders and their interaction, which is affected by the policy measures, the MAS modelling approach is used to represent their multi-objective environment. This paper discusses the MAS in the context of city logistics measures that are aimed at changing the stakeholders' behaviour. In addition, the performance measures evaluated will include the truck emissions and other costs of the stakeholders.

METHODOLOGY

The MAS model for evaluating the joint delivery systems requires the identification of stakeholders that include the logistics communities or logistics associations. Stakeholders are individuals, who belong to various identified "communities" and whose lives or businesses are affected by particular policies. Similarly, the policies may also affect the environment and transportation costs, which may ultimately affect the consumers. The stakeholders identified in a joint delivery system include the freight carriers, a neutral carrier, shop owners, residents, administrators and logistics association that consolidate goods from various freight carriers and load it onto a neutral carrier to dispatch to shop owners by considering operation cost, truck assignment and time window. The urban freight logistics experts have emphasized the importance of engagement of the stakeholders in terms of greater urban distribution centre usage, environmental issues as well as the potential of the joint delivery systems. The MAS model framework consists of the vehicle routing problem with soft time window VRPSTW (Qureshi, 2008) and the behavioural interaction among stakeholders with reinforcement learning model. The interaction among the stakeholders can be described with the MAS interaction model as shown in Figure 1. Figure 2 shows a modified MAS model framework with vehicle routing and scheduling problem with time windows from Tamagawa (2010), which consists of two sub-models; one is the learning model for stakeholders, and the other is the model for vehicle routing and scheduling problem with soft time window (VRPSTW). The learning model evaluates the behaviour of stakeholders, learns and selects the behaviour with their associated objective value. The purpose of VRPSTW in the MAS model is to plan and implement delivery schedules of trucks for each freight carrier and neutral carrier. These two models are executed sequentially.

MULTI-AGENT SYSTEM MODEL FRAMEWORK

The Multi-Agent System (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 methodical, 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; Wooldridge, 2009).

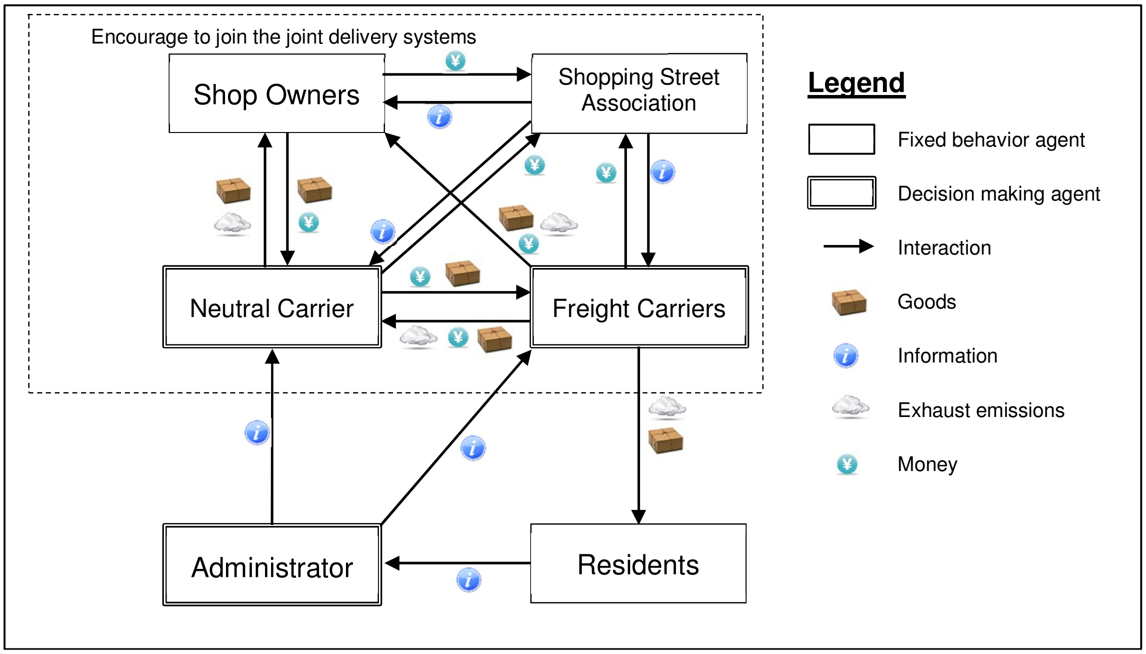


Figure 1 - Stakeholders' interaction within the MAS model

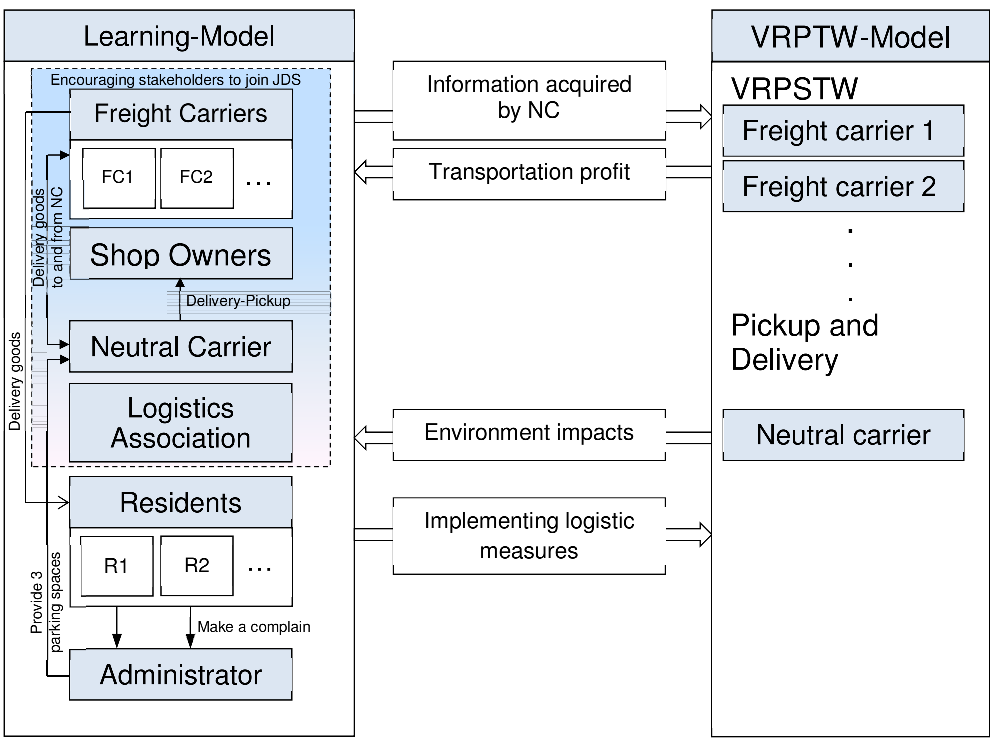


Figure 2 - Proposed MAS model framework with vehicle routing and scheduling problem with time window (modified from Tamagawa, 2010)

Vehicle Routing Problem with Time Window (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 by planning and implementing delivery routing and schedules of trucks for neutral carrier (UDC truck operation). Likewise, this paper seeks to modify the MAS model framework for vehicle routing and scheduling problem with time window-forecasted (VRPTW-F) (Tamagawa, 2010) as shown in Figure 2.

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

The model can be formulated as follows:

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

subject to

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

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

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

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

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

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

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

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

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

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 (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 required to provide good and fast solutions for MAS model. The model described here uses insertion heuristics to solve the VRPSTW.

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 freight carriers and shopping street association can be represented by equation (11).

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

where ,
$Q(s_t, a_t)$: Q-value in state *t* due to action in state *t*.
$Q(s_{t+1}, a_{t+1})$: Q-value in state *t+1* of all actions
γ : discount rate for agent ($0 < \gamma < 1$)
α : learning rate for agent ($0 < \alpha < 1$)
r_{s_t,a_t} : immediate reward in state *t* due to action in state *t.*

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

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

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 in kilometres per hour*

Stakeholder's objectives and interactions

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

Freight Carriers

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

⬇

Behaviour: Propose the fee for transporting goods to shop owners and residents.

Shop Owners

Objective: Minimize delivery cost.

⬇

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

Residents

Objective: Minimize the emissions by trucks.

⬇

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

Administrator

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

⬇

Behaviour: Encourage freight carriers and shop owners to use UDC with subsidies. Issue parking space regulation limitation.

Neutral carriers

Objective: Maximize the profit of delivery goods.

⬇

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

Experiment Setup

Figure 3 shows the test road network used in this study. This hypothetical test road network is representative of Motomachi Shopping Street in Yokohama, Japan. The 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. This network is assumed to be an urban area with congested traffic conditions and crowded shopping street. The four freight carriers have their own depot. The assumption and city logistic measure policies that are used in this study are described in Table I and Table II respectively. The MAS model is iterated for 360 days, which is equivalent to a year. The experiment flow 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 deliver and pickup 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.

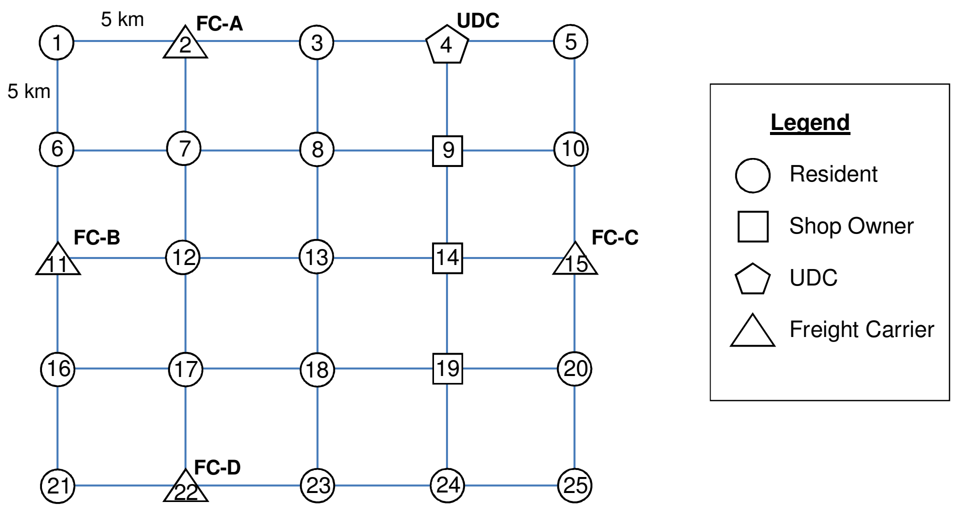


Figure 3 - Test road network

Table I - Modelling assumptions

Modelling assumption
<u>General assumption</u>
Service time for delivery is from 8 AM. to 8 PM.
There is only one type of truck.
There is only one type of goods.
The quantities of delivery and pickup goods are dynamically assigned throughout the year.
The time window of delivery and pickup goods is dynamically assigned throughout the year.
<u>UDC</u>
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.
Various UDC usage charges are “free of charge”, 100 yen/parcel and 150 yen/parcel.
<u>Freight carriers and neutral carrier trucks</u>
Vehicular costs are fixed.
Truck capacity is 130 parcels.

Table I - Modelling assumptions (cont.)

Modelling assumption
<u>Freight carriers and neutral carrier trucks (cont.)</u>
Service time window ranges between 15 to 35 minutes
Freight carriers travel with an average velocity at 30 km/h.
Penalty charge for early delivery is 10 yen/minute.
Penalty charge for delay delivery is 50 yen/minute.

Table II - Condition of Policy Measure

Policy Measure	Affected Agent	Condition
Parking Management	- Neutral carrier - Freight Carriers - Administrator	- Neutral carrier has the first priority of parking space without any charge. - Parking truck at normal car park with 100 yen charged per 10 minutes and continuation of delivery to shop owners on foot with additional service charge of 100 yen per minute.

RESULT AND DISCUSSION

The experiment done included the base case where no learning has taken place within the MAS model and the comparison of the performance measure by implementing the car parking management. Figure 4 shows the trend of frequency of UDC usage decline when the service charge increases resulting in more occurrence of freight carriers delivering the goods directly to their customers.

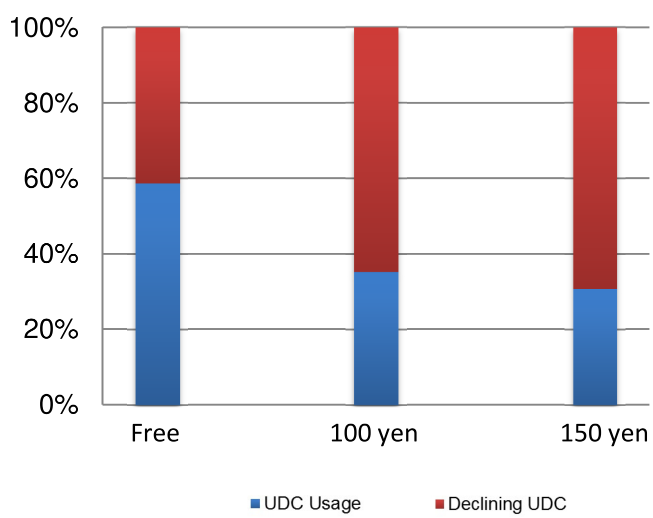
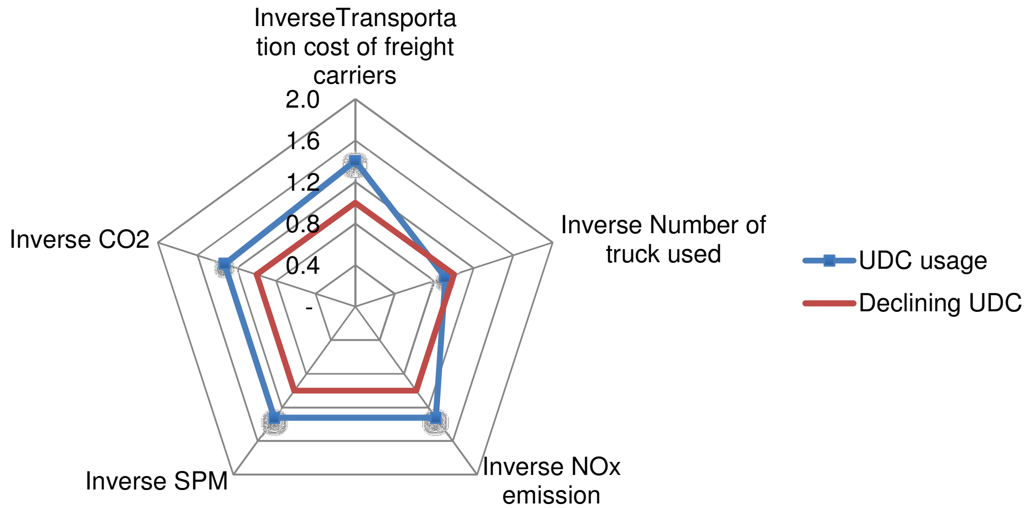
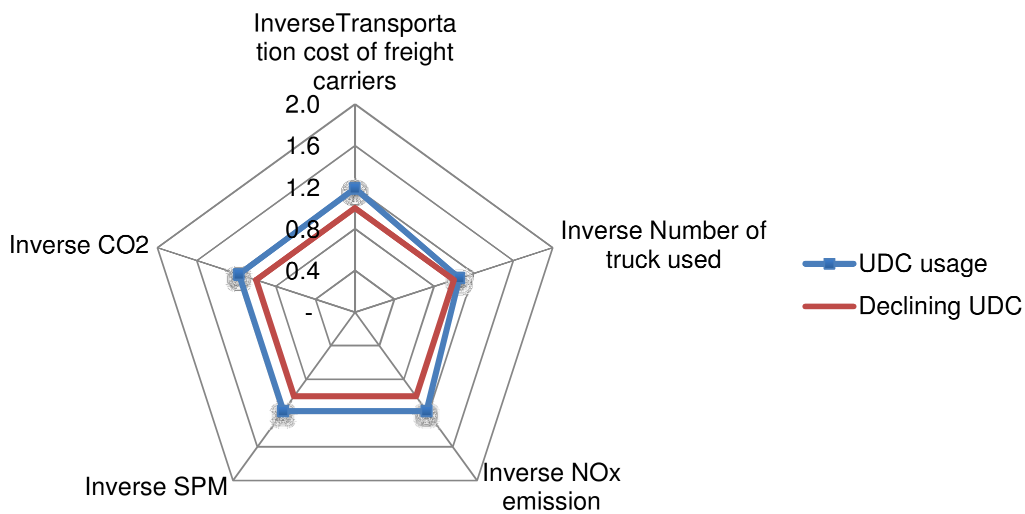


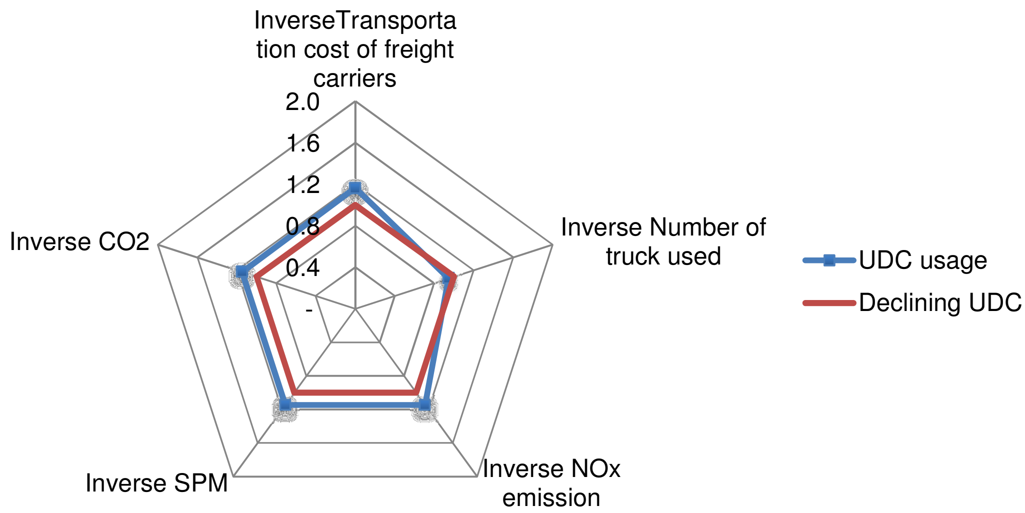
Figure 4 Frequency comparison of various UDC usage fee



a) Comparison of “Without UDC” and “With UDC” charged without a fee



b) Comparison of “Without UDC” and “With UDC” with 100 yen charged per parcel



c) Comparison of "Without UDC" and "With UDC" with 150 yen charged per parcel

Figure 5 Performance of using UDC with various charging

Figure 5 shows the performance measures of using UDC with various service charges compared to the base case. The way to interpret the web plot is to consider the performance measures of "Without UDC" case having the value of one and anything more than one is considered beneficial. A significant observation when the UDC is free is the higher number of trucks used compared to the base case when UDC is not used. One reason may be the large number of parcels that neutral carrier must delivered to residents and shop owners. However, this observation is reversed when the parcel to be delivered is charged at 100yen per parcel.

CONCLUSION

In this paper, the multi-agent system model was used as a methodology to evaluate the benefits, which comprised of transportation cost and environmental issues, of using the urban distribution centre
The findings of operating cost reduction and minimized environmental impact for implementing UDC is encouraging and applying parking management as the additional supporting scheme helps 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. However, the number of trucks used increased when the UDC is free led to the decision to test out the varying price of UDC usage. In one of the case, a charge of 100 yen per parcel eventually led to an overall benefit with the number of trucks reduced. Future studies will continue to evaluate other schemes like subsidy from shopping street association and their impact on the joint delivery systems.

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