Practical Application of Multi-agent Models with GIS to Access City Logistics Measures in Osaka City

Joel S.E TEO[1], Eiichi TANIGUCHI[2], Ali G. QURESHI[3] and Ornkamon WANGAPISIT[4]

[1]Post-doctoral Researcher, Dept. of Urban Management, Kyoto University
(C1-2-338 Kyotodaigaku-Katsura, Nishikyo-ku, Kyoto 615-8540, Japan)
E-mail:joel.teo@kiban.kuciv.kyoto-u.ac.jp
[2]Fellow Member of JSCE, Professor, Dept. of Urban Management, Kyoto University
(C1-2-335 Kyotodaigaku-Katsura, Nishikyo-ku, Kyoto 615-8540, Japan)
E-mail:taniguchi@kiban.kuciv.kyoto-u.ac.jp
[3]Member of JSCE, Assoc. Professor, Dept. of Urban Management, Kyoto University
(C1-3-183 Kyotodaigaku-Katsura, Nishikyo-ku, Kyoto 615-8540, Japan)
E-mail:aligul@kiban.kuciv.kyoto-u.ac.jp
[4]Student Member of JSCE, PhD. Candidate, Dept. of Urban Management, Kyoto University
(C1-2-338 Kyotodaigaku-Katsura, Nishikyo-ku, Kyoto 615-8540, Japan)
E-mail:ornkamon.w@kiban.kuciv.kyoto-u.ac.jp

The road authorities are constantly faced with challenges of increased traffic on the roads that will inevitably lead to negative environment impact. In many developed and developing countries, the effects of urbanization have caused the rise of inhabitants in the city. Such city migration is also attracting more movement of commodities into the city centre. This research aims to provide an evaluation tool to support the authorities when they analyse appropriate city logistics measures that will help to manage the urban freight movement by trucks. The urban distribution centre, which is an effective city logistics measure, is tested in the Osaka City to facilitate delivery of goods to the Shinsaibashi shopping area. The decision tool incorporates the vehicle routing problem with time window model, reinforcement Q-learning model and is supported by geographic information systems. The evaluated city logistics measures seek to achieve an overall benefit for all stakeholders including cost savings for carriers, shippers and diverting trucks away from congested roads and intersections to reduce emissions.

Key Words : *urban consolidation centres, city logistics, multi-agent, vehicle routing problem, GIS, reinforcement learning*

1. INTRODUCTION

Urban freight transport is gaining more attention in many megacities of the world due to the movement of more population into urban areas as well as social and environmental problems that are related to urban freight transport. The government is constantly required to tackle problems in urban areas that include creating efficient urban freight transport systems with higher services and lower costs and to ensure the better environment, safer community and well-being of people who are living within. The concept of city logistics has been introduced[1, 2] for establishing efficient and environmentally friendly urban freight transport systems towards sustainable and liveable cities by balancing the above mentioned issues. The essential aspect of city logistics is that although the logistics activity is mainly carried out by private companies, the intervention of public authorities are required to achieve the goals of city logistics by implementing policy measures[3]. In the procedure of public private partnerships for identifying current problems, discussing appropriate approaches and measures as well as evaluating them and feedback are important. Sharing data and information among stakeholders and assessing the policy measures before implementing them would also be essential. In this procedure, modelling city logistics policy measures, including truck ban, access control, road pricing, setting urban consolidation centres (UCC), off-peak hour delivery, load factor controls and new highway locations play a crucial role for the evaluation.

This paper evaluates the prospects of urban distribution centre in Osaka City based on the experience of successful implementations like Motomachi in Yokohama, Japan.

2. LITERATURE REVIEW

The UCC has been studied and encouraged as a promising concept, where carriers with common customer locations deliver their goods to a single facility. The goods are consolidated into neutral trucks operated by the facility and these trucks continue the last-mile journey to reach the final receivers. Such operation is said to increase the load factor of the trucks and to allow for easier time-windowed operations to avoid traffic congestion[4)].

There are few but successful implementation of urban distribution centres around the world. One of them is the Cityporto case in Italy where the UCC is part of an initial public-private partnership among the Municipality, Province and Chamber of Commerce since 2004[5)]. The UCC operates on methane-powered trucks that are less harmful to the environment compared to diesel trucks. Some of the UCC success factors in Cityporto case included the proximity of consolidation centre within the freight village and favourable policies and general public support, which spurred the management to provide efficient operations. The Interporto Padova S.p.A. that functioned as the neutral operator of UCC also helped to prevent any market distortion. Another case of successful UCC operation is Motomachi at Yokohama, Japan, which started initially as a pilot project between 1999 to 2001 before the actual implementation in 2004. The success factors for this UCC include good leadership, coorperative collaboration of stakeholders, good business model, use of CNG-powered trucks and pre-assigned parking locations for UCC operated trucks

The current single company managed supply chains are constantly faced with the challenge of the "last-mile" delivery or collection of goods, especially in urban areas. The demand points in the last mile for urban areas are usually located away from the distribution centres and in places where there are several restrictions or constraints on the road usage. Such complexities accompanied by other social, environmental and economic costs add to the company's difficulty in trying to maintain the economies of scale for delivery. Singapore is another country that is facing rapid urbanisation and the Singapore Science and Engineering Research Council's (SERC) Urban Systems Initiative proposed the idea of collaborative urban logistics concept[6)]. The features of the collaborative urban logistics concept include clusters of Logistics Service Providers (LSPs), customers and suppliers interacting in a coordinated electronic marketplace (e-marketplace). Within the e-marketplace, LSPs can share their job schedule and route planning online and the electronic market will act as the coordinator by searching for clients upstream (supplier cluster) or downstream (demand points) by fulfilling each client's time window, multi-objective vehicle routing options or other needs. The aim of the e-marketplace is to encourage consolidation and facilitate open bidding and negotiation. Such system will also lead to trucks achieving higher load factor, lesser trucks used, less emission and improve on the road congestion. The collaborative urban logistics concept is supported by four main thrusts and one of them is the multi-party coordination thrust, which utilises the concept of consolidation centres but integrates an iterated combinatorial auction mechanism where each agent bids for the services and the final price adjustment is done by a centralised auctioneer.

Recent studies by researchers have considered urban freight logistics by using the multi-agent systems (MAS) modelling approach to evaluate urban consolidation centre[7, 8, 9)]. This research will continue to explore the use of MAS with the support of geographical information systems (GIS) to evaluate the advantages and disadvantages of UCC in a large-scale and real road network environment.

3. METHODOLOGY

This research follows the MAS framework as shown in **Fig.1**. This framework utilises the similar Q-learning method employed for the agents in past study [9)] with an additional UCC learning agent.

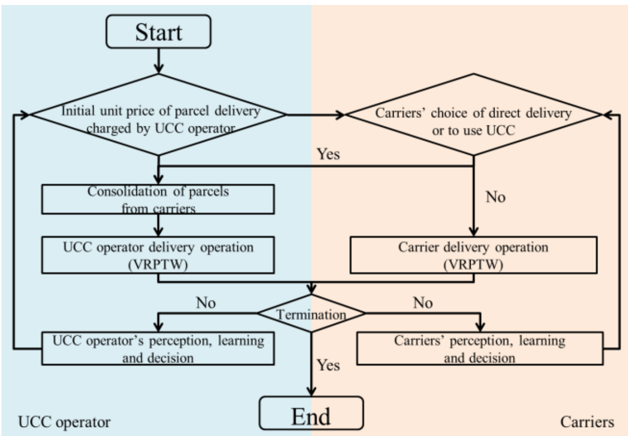

Fig.1 MAS simulation framework

(1) General assumption for consideration

Since no real truck movement data is collected for this initial experiment, the following considerations are recommended for subsequent analysis when data like the probe data of truck movement becomes available.

Even with the probe data of truck delivery operations, there will be limitations in determining the locations and demand precisely and certain steps are required to obtain useful information for computation purposes and to compare the results.

a) Locations

The locations of each depot's customers can be based on the start and stop trip of the delivery truck. However, this start and stop trip data may consists of signal stops or temporary stops for other purposes. To eliminate such data in the analysis, any trips with duration of less than 80 seconds between the stop trip and the next start trip should be removed.

b) Demand

The demand at each customer location during probe data collection may not be easily available due to privacy issues. A possible method to determine demand at customer locations can be based on the equation (1). The capacity of the truck in the vehicle routing problem with time window (VRPTW) computation can be the common capacity of the trucks used by all carriers during the data collection like a 3 ton truck and the truck load factor of 60% can be assumed. This load factor is set as a threshold measurement for a scheme named City Goods Ordinance in Copenhagen from February 2002 to 31 October 2003, which issued a green certificate if the trucks achieved a load factor of more than 60% over a 3-month period and an engine that met the criteria of not being older than 8 years[10].

$$d_i = q \times lf \times \frac{st_i}{\sum_i^N st_i} \qquad \forall i \in N \tag{1}$$

where,

d_i = demand at customer i

q = capacity of truck

lf = load factor

st_i = stopping time at customer i

N = set of customers

c) Time window

The time window of customers may not be available during the data collection since it may also be classified by the private carriers. An assumption can be made for the time window requested by the customers for the VRP computation. **Fig.2** shows the illustration of the hard time window with 10 minutes before the truck stopping time as early time window and 10 minutes after truck departure as the late time window.

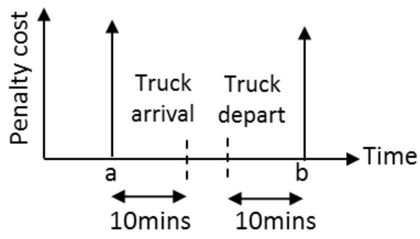

Fig.2 Time window assumption for carriers' customers

4. EXPERIMENT SETUP

In the initial experiment, the selection for the location of the UCC was done based on the following criteria. Firstly it should not be located within the city centre. Secondly, It should have well connected roads to link the carriers' depots. The test network is shown in **Fig.3**.

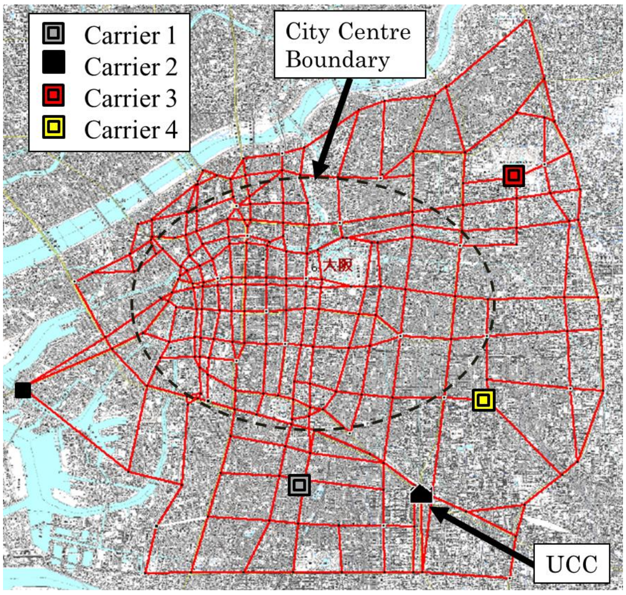

Fig.3. Road network with VICS data

The stakeholders involved in this analysis are the UCC operator and the four carriers. Based on a general survey done for UCCs in Japan, a typical parcel costs about 150yen to deliver. In our analysis, the pricing of delivery depended on the weight of the commodity. A range of pricing rate with the maximum rate of 6 yen per kilogram was used for the experiment. A fully loaded UCC 2 ton truck will probably cost a maximum of 12,000 yen for a carrier and will carry a variety of large and small parcels. The pricing rate during the simulation was adjusted every iteration by the UCC operator based on its Q-learning model. The effectiveness of the UCC is compared to a base scenario where a UCC is not present. In the base case, each depot served 12 customers with randomness assignment in their locations, time window for delivery and demand of goods in terms of kilogram. Each carrier in the base case is modelled to deliver the goods directly to their customers using the optimised routes to minimise their operation cost. This behaviour is altered when a UCC is present. Each carrier can choose whether to send their goods directly from their depot or to send their goods to the UCC for consolidation and delivery by the UCC trucks to their customers. The above decision is based on the Q-learning model of each carrier, which considered their past experience of using the UCC and the possible potential of using the UCC in the future.

5. RESULTS AND DISCUSSION

The radar plot shown in **Fig.4** shows the benefits of the UCC. Due to the reduction of trucks by about 17% when the UCC is introduced, the emission level of the environment has improved by about 20%. The cost to the carriers has improved probably due to the attractive rates of the UCC.

In the analysis of UCC operation, the operating expense ratio is used to determine the percentage of revenue received from carriers' participation that are used to cover the operating delivery operating cost of the UCC trucks. The cost of land and other capital investment of the UCC are not considered in this experiment. The operating expense ratio is shown in equation (2).

$$OER = \frac{OC}{R} \times 100\% \qquad (2)$$

where,

OER = operating expense ratio

OC = operating cost of delivering goods from UCC to customers

R = revenue, ie. product of total goods received from carriers and unit rate per kilogram

Based on the results of the experiment, the operating cost, *OC*, was 2,744,425 yen while the revenue received by the UCC operator was only 1,025,006 yen. The *OER* for this instance is much more than 100%, which meant that the operation of UCC is not having an operating profit. However, with the potential of UCC improving the emission level, reducing the number of trucks on the road and carriers' cost, the *OER* can be improved if there are some subsidies for the UCC operators to cover their operating cost.

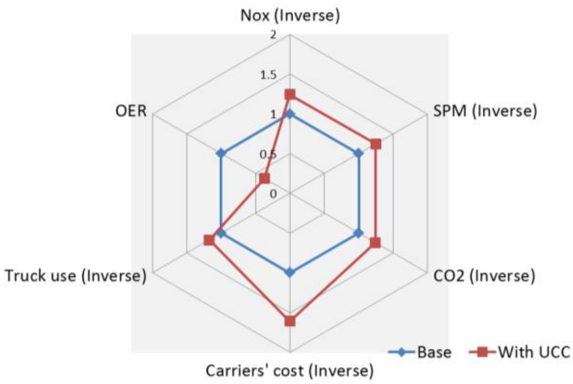

Fig.4 Radar plot of initial results

6. FURTHER RESEARCH

The initial experiment on the test network expanded more opportunities to consider for the UCC in Osaka city. A similar scenario like the Motomachi shopping street in Yokohama is currently tested for Shinsaibashi area in Osaka. **Fig.5** shows the GIS network with residential landuse area that will generate the demand of goods. It is expected that the MAS model will be able to produce some emerging behaviour of the stakeholders and more results for this experiment shall be discussed during the conference presentation.

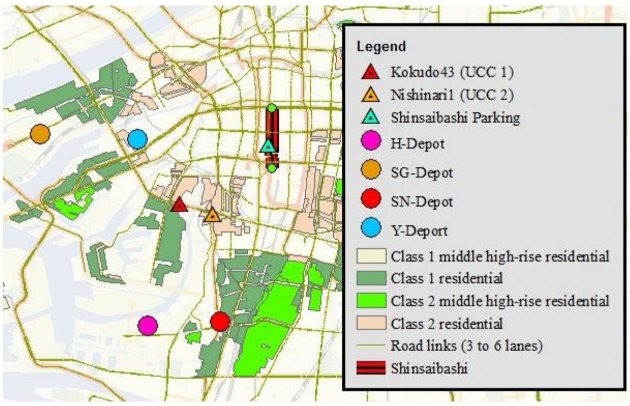

Fig.5 Road network coverage in Osaka City

ACKNOWLEDGMENT: This work was supported by JSPS KAKENHI Grant Number 26820212.

REFERENCES

1) Taniguchi, E., Thompson, R. G. Thompson, Yamada, T. and van Duin, R. : City Logistics: Network Modelling and Intelligent Transport Systems. Pergamon, Oxford, The Netherlands, 2001.
2) Crainic, T. G., Ricciardi, N. and Storchi, G. : Models for evaluating and planning City Logistics systems, *Transportation Science*, Vol. 43, pp. 432–454, 2009.
3) Technical committee B.4 freight transport and intermodality. Public sector governance over urban freight transport. 2012.
4) Quak, H. and Koster, M. : Delivering goods in urban areas: How to deal with urban policy restrictions and the environment, *Journal Transportation Science*, 43(2), 221-227, 2009.
5) Leonardi, J., Browne, M., Allen, J., Bohne, S. and Ruesch, M. : Best practice factory for freight transport in Europe: Demonstrating how 'Good' urban freight cases are improving business profit and public sectors benefits. *Procedia – Social and Behavioral Sciences*, 125C, pp. 84-98, 2014.
6) de Souza, R., Goh, M., Lau, H-C., Ng, W-S and Tan, P-S. : Collaborative urban logistics – Synchronizing the last mile: A Singapore research perspective. *Procedia – Social and Behavioral Sciences*, 125C, pp. 422-431, 2014.
7) Antal, V. K. : Multi-agent model for the urban distribution centre: Scenario search and dynamic urban distribution centre pricing to find a positive business case, *Master Thesis*, Delft University of Technology, 2010.
8) van Duin, J. H. R., Kolck, A., Anand, N., Tavasszy, L. and Taniguchi, E. : Towards an agent-based modelling approach for the evaluation of dynamic usage of urban distribution centres, *Procedia - Social and Behavioral Sciences*, 39, pp. 333-348, 2012.
9) Wangapisit, O., Taniguchi, E. Teo, J.S.E. and Qureshi, A.G. Multi-Agent Systems Modelling For Evaluating Joint Delivery Systems. *Procedia – Social and Behavioral Sciences*, 125C, pp. 472-483, 2014.
10) Kjaersgaard, S. and Jensen, H. E. : Sustainable city logistics solutions. In E. Taniguchi & R. G. Thompson (Eds.), Logistics Systems for Sustainable Cities – Proceedings of the 3rd International Conference on City Logistics (Madeira, Portugal, 25-27 June 2003) (pp. 441-448). Kidlington, Oxford, UK: Elsevier Ltd, 2004.

(Received April 25, 2014)