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 context of city logistics measures that is aimed at changing the stakeholders' behavior and the environmental impacts when they are encouraged to join the joint delivery system with the help of an urban distribution centre and parking space management for loading/unloading. The preliminary results of the model show that the joint delivery system has capability to reduce total distance travelled, operation costs, truck emissions and to increase loading factor.

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

1. INTRODUCTION

Recently, the population in megacities continues to increase especially in developed countries such as Tokyo, New York, Delhi and Paris. They have advance systems for habitation, sanitation, transportation and various utilities. The high density of people and utilities greatly facilitate business as relatively large portion of GDP is earned inside highly urbanized areas (OECD, 2007). These have caused tremendous demand of delivery businesses and freight traffic on top of the existing passenger transport that has caused traffic congestion, traffic accidents, illegal parking (loading/unloading on street sides) and affected environmental issues (Duin, 2012). Consequently, this research aims to focus on delivery business in the urban area. In other words, urban freight logistics have became serious problems in city planning, which is considered in city logistics as defined by Taniguchi (Taniguchi, 1999) as:

"City logistics is 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".

Urban freight logistics systems are critical to delivery business. The transportation system is core of the logistics that affects the product costs, customer satisfaction by just in time delivery with effectiveness and efficiency vehicle routing and scheduling. To enhance and reduce the urban freight logistics problems, the urban distribution centre is recommended (Dablanc, 2007). The urban distribution centre is an encouraging concept, where the loads of delivery trucks from different carriers is 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 can decrease harmful effects associated with city logistics (Duin, 2012). Previously, several researches have shown the successful utilization of urban distribution centre (Marcucci, 2008). In contrast to reality, the concept has failed due to stakeholders' behavior as freight transport itself is under high pressure with strong competition and the Just-In-Time (JIT) delivery system (Germain, 1996). These differences might be due to the fact that most models use the average values of travel time, delivery demand and fixed time window for estimations. The stakeholders' reactions are also not modeled accurately in the models. Hence, there is a desire to find out if the encouraging concept of the urban distribution centre can contribute to enhance city logistics.

2. OBJECTIVES

The objective of this research is to study the impact of city logistics measures by implementing an urban distribution centre, managing illegal parked vehicles and time window restriction. To study the behavior of urban freight stakeholders, who interact in urban logistics systems being affected by policy measures, the multi-agent modeling systems (MAS) is a useful methodology to represent their multi-objective nature. This research discusses the MAS in context of city logistics measures that are aimed at changing the stakeholders' behavior and reducing the environment impacts. The joint delivery system is considered together with parking management to reduce illegal parking of vehicles, which will affect other stakeholders' objectives.

3. MULTI-AGENT MODEL FRAMEWORK

(1) Multi-agent system (MAS)

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 methodic, functional, procedural or algorithmic search, find and processing approach. MAS is a useful methodology to consider the multi-objective nature of an urban logistics system and study the behavior of the stakeholders who are influenced by policy measures. MAS consist of an environment with multiple autonomous agents with the ability to sense, perceive and take action while incorporating the interactions of other agents (Joel, 2012). Additional information in MAS can be found in related sources (Weiss, 1999 and Wooldridge, 2009).

This research proposes to use MAS modelling approach to evaluate the utilization of urban distribution centre, behavior of logistics stakeholders and the impact of illegally parked vehicle. Furthermore, this research seeks to study the behavior of urban freight stakeholders, who interact in urban logistics systems being affected by policy measures.

(2) VRPTW

VRPTW model plans and implements delivery routing and schedules of trucks for each freight carrier. This research aims to study the delivery and pickup activities at the 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 research seeks to follow and modify the 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 Figure 1.

To determine the optimal solution by minimizing the total transport cost of freight carriers and neutral carrier, the research is applied model by Qureshi A.G. (2008) which vehicle routing and scheduling probem with soft time windows (VRPSTW) to analysis pickup and delivery goods activities.

The model can be formulated as follows:

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

subject to

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

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

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

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

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

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

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

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

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

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 (Eq. (2)) minimizes the sum of delivery costs that consist of the fixed vehicle utilization cost, travel cost on arcs and the penalty costs. Constraint (3) ensures that each customer is serviced only once and constraint (4) makes sure that the load carried by the vehicle is within the limit of the vehicle's capacity. Constraints (5) and (6) determine that the vehicle shall start and end at the depot while constraint (7) ensures that the vehicle entering vector h must also leave from vector h. Constraint (8) restricts the arrival time to be within the relaxed time window of a_i' and b_i' and constraint (9) ensures that the service start time is within a_i and b_i'. Constraint (10) 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, (11) 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 identify good solutions. The model described here uses Insertion Heuristics to solve the problem.

(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 substantial improvements, bringing Probably approximately correct learning (PAC) bounds to Markov decision processes (Alexander, 2006).

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

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 adminrator ($0 < \gamma < 1$)

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

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 recent 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 is concern only on current rewards. The oxides of nitrogen (NO_x) emission is estimated using equation (12) (NILIM, 2003) assuming delivery truck vehicles using 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

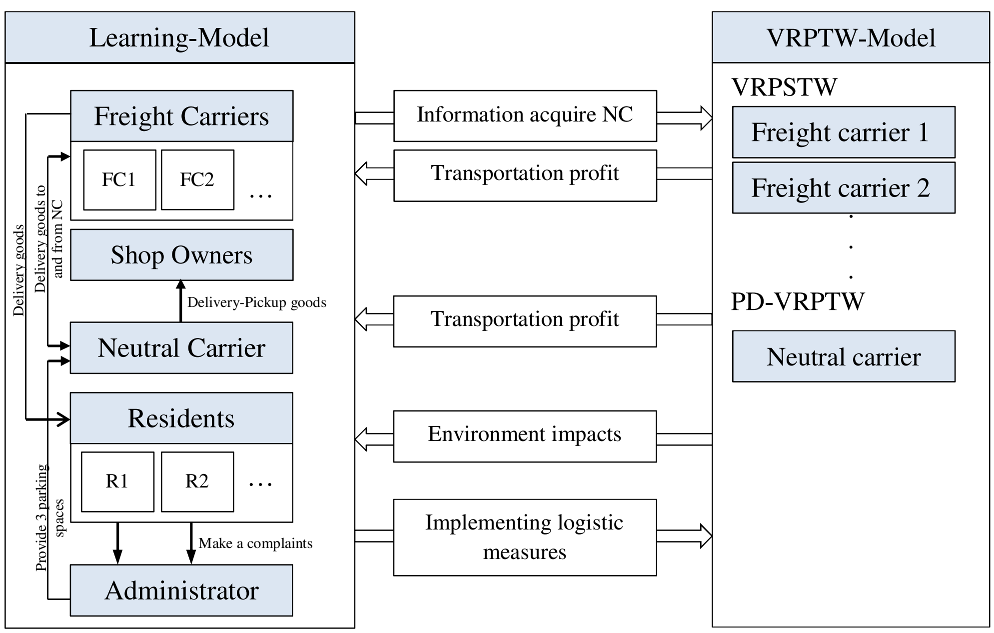

Figure 1: New MAS model framework with vehicle routing and scheduling problem with time window

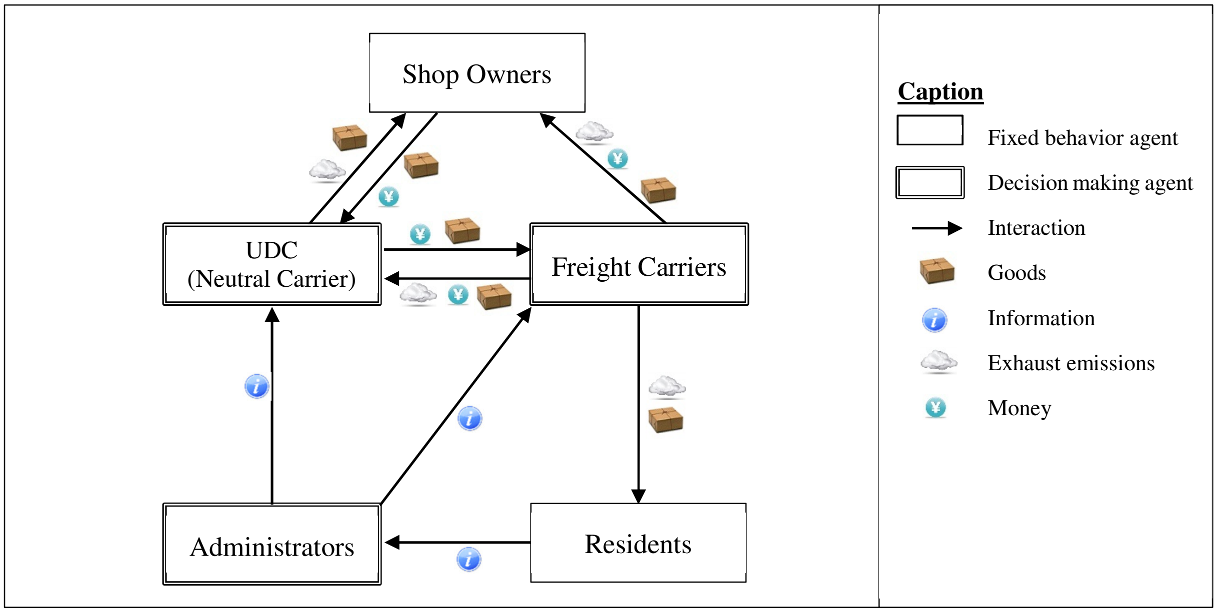

Figure 2: Stakeholder interaction order

(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 earn more benefit.

⬇

Behavior: Propose the price of transporting goods to shop owners and residents without delay.

Shop Owners

Objective: Minimize delivery cost.

⬇

Behavior: Desire just in time delivery.

Residents

Objective: Minimize the probability of exceeding the environmental limit of NO_x emissions by trucks.

⬇

Behavior: 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.

⬇

Behavior: Encourage freight carriers and shop owners to use UDC.

Neutral carriers

Objective: Maximize profit of delivery goods.

⬇

Behavior: Propose the price of transporting goods to shop owners without delay.

Shopping Street Association

Objective: Maximize profit of arrangement the shopping street.

⬇

Behavior: To execute and operate the shopping street and communicate among shop owners.

3. RESULT AND DISCUSSION

(1) Hypothetical road network

The hypothetical test road network is shown in Figure 3. Four carriers are named as carriers A, B, C

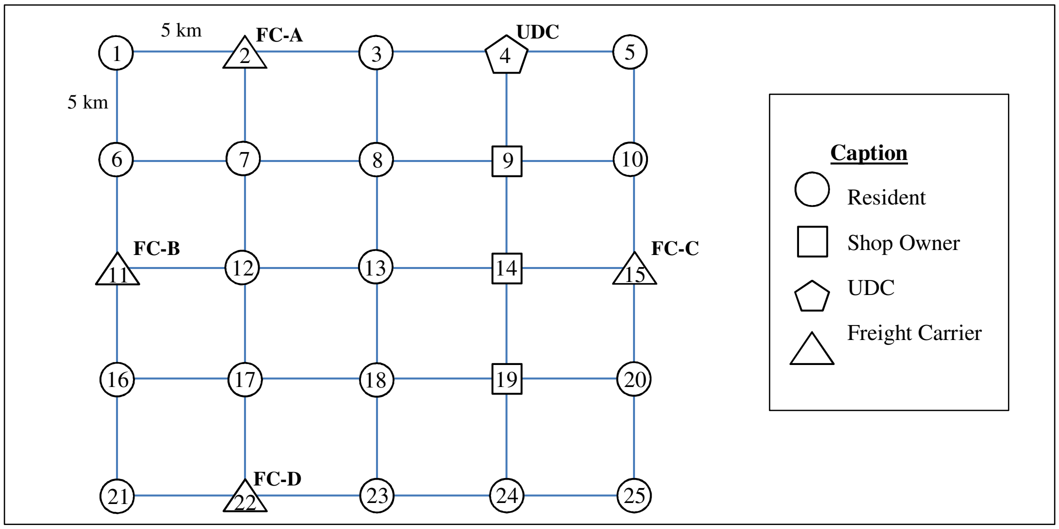

Figure 3: Test road network

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 randomly assigned quantities of delivery and pickup goods is fixed throughout the year.
The randomly assigned time window of delivery and pickup goods is fixed through the year.
Model illustrates an artificial city.
Outer city delivery operation costs are not included.
Freight carriers
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.
UDC
Location of UDC is closed to access the city for freight carriers.
The UDC can have an early delivery, fixed time deliveries or full truck delivery scheme.
UDC usage charge is 150 yen/parcel.
Neutral carrier
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.
Freight carriers and neutral carrier trucks
Vehicular costs are fixed.
Variable trucks costs are 115 yen/minute per truck.
Truck capacity is 130 parcels.
Service time windows is 15 to 35 miniutes

and D and are located at nodes 2, 11, 15 and 22 respectively. Nodes 9, 14 and 19 are the locations of shop owners while the rest of the nodes represent the residents. The MAS model is iterated for a year with 365 days.

(2) Results

In this paper we would like to address a modelling approach based on multi-agent modelling which is organised with vehicle routing and incorporated with an urban distribution centre and the joint delivery systems. These could decrease financial viability of UDC, the environmental impacts in the city and increase load factor.

The results of the evaluating urban policy measures on UDC would be presented at the conference.

5. CONCLUSION

This research aimed to evaluate city logistics measures like the parking space management and the implementation of joint delivery system. The complexity of the real world urban logistics systems analysis encouraged the use of the MAS methodology to model freight transportation, where policies can be accessed for reason of relevance, cost and time effectiveness.

The initial findings of operating cost reduction and minimal 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 MAS model can be further improved by generating realistic demand and testing on real road network, which will be considered in the future research.

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