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論文題目	MULTI-AGENT MODELING TO EVALUATE URBAN FREIGHT TRANSPORT POLICY MEASURES USING JOINT DELIVERY SYSTEMS（共同配送システムを用いた都市物流施策評価のためのマルチエージェントモデリング）		

（論文内容の要旨）

This thesis deals with multi-agent modeling to evaluate urban freight transport policy measures using joint delivery systems. It consists of 6 chapters, which can be summarized as follows.

Chapter 1 presents an introduction. The urban freight transportation problems of the shopping street have been addressed to identify possible schemes to improve the city logistics. This situation happens as a consequence of stakeholder’s behavior due to the change of urban lifestyles, which increases the freight traffic. The purpose of this thesis is to study the effects of combination of city logistics policy measures such as Joint Delivery Systems (JDS), Urban Distribution Center (UDC) and parking space restriction. Moreover, to study the behavior of urban freight stakeholders and their interactions, which are affected by the policy measures, the Multi-Agent Systems (MAS) modeling approach is used to represent the corresponding multi-objective environment.

Chapter 2 summarizes the literature review. The preceding literature indicated that one of the solutions for improving and reducing the urban freight logistics problems is to introduce the UDCs. Several researchers have studied on urban freight logistics using the Multi-Agent Systems (MAS) modeling approach to evaluate city logistics measures, including road pricing, toll pricing, truck ban, time windows restrictions, load factor control, operation subsidies and UDC usage. Nevertheless, the studies about evaluation of city logistics stakeholder’s behavior under a combination of policies such as implementation of the UDCs, joint delivery system and parking space restriction, have never been presented in the literature. Therefore, the aim of this research is to explore whether the implementation of JDS and parking management as the city logistics measures can improve the overall benefits by using the MAS models with reinforcement learning.

Chapter 3 highlishts the mathematical models of stakeholder’s behavior. The study about the models used in the UDC analysis and its impacts on the stakeholder’s behavior was carried out. The Vehicle Routing Problem with Soft Time Windows model was applied and solved using genetic algorithms for carriers’ routing decision as individual company and under the UDC and Joint Delivery Systems (JDS) schemes. To consider whether the carriers would join or not join the JDS with UDC, the learning system of Q-learning that is a form of reinforcement learning was used. The performance measures for the experiment include the emissions of CO_2, NOx and SPM, UDC usage, and the carrier's cost.

Chapter 4 focuses on the application of models on the hypothetical road network. The model was applied on the hypothetical road network with 25 nodes that represents Motomachi shopping street in Yokohama. Four scenarios were tested including a base case without UDC. Scenario II considered that the UDC is compulsory and free to use to deliver goods to residents and shop owners. Scenario III, studied the stakeholder’s behavior using MAS when the carriers were given a choice to join the UDC or not based on their learning. Finally, Scenario IV, added the parking restriction to the scenario III to evaluate the effects of the combination of these policies. It can be concluded that the along with the reduction in operating cost after implementing UDC and applying parking management as an additional supporting scheme can improve the overall effectiveness of city logistics. The reduction of emissions of CO_2, NOx and SPM by urban freight transport was achieved due to the reduction in distance travelled resulting from the replacement of individual delivery to consolidated delivery with UDC. However, it is found that a lower charge of 10 yen per parcel for UDC usage eventually led to an overall benefits.

Chapter 5 presents modeling application on Osaka road network. This chapter evaluates the

prospects of UDC in Osaka City based on the experience of successful implementations like Motomachi Shopping Street (MSS) in Yokohama, Japan. The target cases is at Shinsaibashi Suji shopping street, Osaka. This research uses the Multi-Agent Systems (MAS) framework. This framework utilises the Q-learning method employed for the agents in chapter 4 with an additional UDC learning agent. The study concludes that the freight carrier's delivery cost may not reduce due to the implementation of UDC usage charge. To deal with this point, the discount service charge and the subsidy from the administrator can be considered. Regarding the environmental impact of implementing UDC in Osaka city, the reductions in CO_2, NOx and SPM emissions due to urban freight transprot were observed as a result of the reduction in distance travelled replacing the individual delivery to consolidated delivery with a UDC.

Chapter 6 provides overall conclusions. As the summaries of this research, the presence of UDC and parking space restriction were identified as possible city logistics policy measures to decrease the negative environmental impacts of the trucks travelled from freight carrier's depot to their customers. The MAS learning model was initially setup to include the JDS as representative of freight carriers and neutral carrier interaction to ensure that delivery cost was minimised. The reinforcement Q-learning model has been used in this research to test the developed MAS model and to incorporate the interaction between the freight carriers and a neutral carrier in the urban freight delivery. It is challenging to determine the agents' learning objectives when each agent may be required to learn what other agents are learning or thinking. Learning by carriers influenced the performance of the UDC and its sustainability within the multi-agent model, compared to the model without learning. The low learning rate means that the carrier is more pessimistic towards its perception of new information. In the current study, it shows that a higher learning rate of carriers may lead to lower participation rate of the UDC and may take a longer time to attract them to use the UDC again. Therefore, the joint decision-making and cooperative behavior can be attained.

The results from the freight carrier's learning showed the potential of reducing truck emissions level of CO_2, NOx and SPM in the city when the freight carriers learned based on the outcome of past actions and future rewards. Operating cost, number of trucks and distance travelled were reduced, which lead to a better environment when UDC was implemented. In contrast, from the economic viewpoints on practical road network, the freight carrier's delivery cost was not reduced because of the implementation of UDC usage charge. To deal with this point, the discount service charge and the subsidy from the administrator can be considered. A higher unit price of parcel for using UDC increases carriers' cost and reduces the carriers' participation in the joint delivery system. Therefore, subsidies can play an important role in the sustainability due to its contribution for better environmental effect. The presence of joint schemes of UDC and parking space restriction were identified as potential city logistics policy measures to decrease the negative environmental impacts and number of trucks used.

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（論文審査の結果の要旨）

本論文は、共同配送システムを用いた都市物流施策を評価するために、複数の利害関係者の行動を記述できるマルチエージェントモデルによるモデル化を行っている。従来から都市物流施策の評価について、複数の利害関係者の行動を考慮した研究はあまり行われていないが、本研究においては、共同配送システム、共同配送センターの設置および駐車規制を組み合わせた都市物流施策について、学習過程を内包するマルチエージェントモデルを用いた評価手法を開発しており、その点に新規性が見られる。本論文の主な成果は以下の 3 点にまとめられる。

（１）効率的かつ環境に優しい都市物流システムを構築するために、共同配送システム、共同配送センターの設置および駐車規制を組み合わせた都市物流施策を対象として、一般の物流事業者、共同配送センターから配送する中立の物流事業者、小売店、行政、住民などの利害関係者の行動を考慮したマルチエージェントモデルを用いた評価手法を開発した。

（２）このマルチエージェントモデルは、２つのサブモデルからなる。１つはソフトタイムウィンドウ付配車配送計画モデルであり、他の１つは、Ｑ－学習モデルである。ソフトタイムウィンドウ付配車配送計画モデルは物流事業者の物資配送行動を記述するモデルであり、Ｑ－学習モデルは、利害関係者の行動の相互連関を表すモデルである。

（３）開発したモデルを仮想道路ネットワークに適用し、共同配送システム、共同配送センターの設置および駐車規制を組み合わせた都市物流施策について、共同配送センターの利用料金、行政による補助金による共同配送センター利用率への影響を明らかにした。また、大阪の道路ネットワークにこのモデルを適用し、共同配送センター設置によるトラック台数の削減、トラックの総走行距離の削減、環境負荷低減などの複数の基準による効果を明らかにした。

以上のように、本論文は都市物流施策を評価するために重要な役割を果たすマルチエージェントモデルを開発し、実際の道路ネットワークへの適用性についても明らかにしており、学術面において大きな貢献を行っているとともに実際面においても寄与するところが少なくない。よって、本論文は博士（工学）の学位論文として価値あるものと認める。また、平成 26 年 8 月 22 日、論文内容とそれに関連した事項について試問を行って、申請者が博士後期課程学位取得基準を満たしていることを確認し、合格と認めた。