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論文題目	MULTI-AGENT SIMULATION USING ADAPTIVE DYNAMIC PROGRAMMING BASED REINFORCEMENT LEARNING FOR EVALUATING JOINT DELIVERY SYSTEMS (共同配送システムを評価するためのアダプティブダイナミックプログラミングに基づく強化学習を用いたマルチエージェントシミュレーション)		
<p>(論文内容の要旨)</p> <p>This research modelled the behavior of freight carriers and Urban Consolidation Center (UCC) operator using Multi-Agent Simulation-Adaptive Dynamic Programming based Reinforcement Learning (MAS-ADP based RL) to evaluate the city logistics measure of Joint Delivery Systems (JDS) under an uncertain environment. The results indicated that the MAS-ADP based RL is better to adapt with the changing environment in city logistics and performs better than the MAS-Q-learning thus increasing the accuracy of decision making of freight carriers and UCC operator. Under the uncertain environment of city logistics, the MAS-ADP based RL could suggest the best decision of delivery method for freight carriers, the profitable UCC fee for the UCC operator and eventually reduce the negative environmental impacts.</p> <p>Chapter 1 Introduction</p> <p>Chapter 1 describes the general introduction of city logistics systems including definition, visions, and stakeholders involved in the systems. JDS with UCC, truck parking policy, combined policies implementation, and smart city logistics are introduced as examples of sustainable city logistics policies. The research motivation for developing learning models within MAS on city logistics problem is explained. It leads to the objectives of this research. Finally, some research contributions and benefits are listed in this chapter.</p> <p>Chapter 2 Literature Review</p> <p>Chapter 2 reviews the literatures related to the study. Markov decision processes as the defined approach of MAS are reviewed in this chapter, followed by its solution methods such as dynamic programming and RL. The current literatures about ADP based RL and Q-learning are examined in more details as they are used as the primary models in this research. Applications using ADP and Q-learning in MAS in the past literatures are also discussed in this chapter.</p> <p>Chapter 3 Learning Model Development</p> <p>Chapter 3 mainly describes the model development process. Starting with the description of agents considered in this research, agent's behavior and learning process using MAS-ADP based RL and MAS-Q-learning has been described. The use of Vehicle Routing Problem with Soft-Time Windows (VRPSTW) to optimize the agent's delivery routing problems is also described. Chapter 3 gives models used to calculate environmental emissions.</p> <p>Chapter 4 Learning model evaluation in the hypothetical network</p> <p>Chapter 4 applies MAS-ADP based RL and MAS-Q-learning models in the hypothetical network, which is also used to study the performance of the two learning models under different environment settings of simulations. The sustainability of JDS policy measures with UCC is also investigated in chapter 4 followed by a discussion on the benefits of learning for freight carriers and UCC operator under some given future scenarios of JDS with UCC. This chapter supports the research benefits and contributions described in chapter 1 with simulation results.</p> <p>Chapter 5 Learning model application for evaluating JDS in relation with the different locations of UCC in Yokohama network</p> <p>The results of chapter 4 are used as benchmark for chapter 5 for evaluating the performance of the developed MAS-ADP based RL and MAS-Q-learning models in a real network of Yokohama. The purpose of chapter 5 is to evaluate the policy measures of JDS in relation with the different locations of UCCs on Yokohama network, Japan using MAS-ADP based RL.</p>			

Chapter 6 Conclusion

Chapter 6 summarizes the conclusions of this research as listed;

1. This research developed the learning models for freight carriers and UCC operator using MAS-ADP based RL as an on-policy learning method to evaluate the policy of JDS under an uncertain environment of city logistics.
2. The simulation results in hypothetical network and Yokohama network indicated that the MAS-ADP based RL is better to adapt with the changing environment in city logistics and performs better than the off-policy based algorithm such as MAS-Q-learning thus increasing the accuracy of decision making of freight carriers and UCC operator, and reducing the negative impact of the environment.
3. This research also shows that the “learning” is essential in the decision-making process of the agent, especially when the agent needs to interact within the multi-agent systems with fluctuating and changing environment such as city logistics. By learning the value received from the environment, learning agents could take more accurate decisions thus optimize their objective. Under the uncertain environment of city logistics, the MAS-ADP based RL increased the benefits of JDS with UCC by suggesting the best delivery method for freight carriers, the profitable UCC fee for the UCC operator and eventually reduce the negative environmental impacts.

(論文審査の結果の要旨)

本論文は、都市内物流システムの効率性を高め、環境負荷を低減するために、アダプティブダイナミックプログラミング (ADP: Adaptive Dynamic Programming) に基づく強化学習を用いたマルチエージェントモデルを構築し、顧客の需要変動がある場合に、物流事業者、共同配送センター管理者などの利害関係者の行動をシミュレートし、様々なシナリオにおける共同配送システムの評価手法を確立しようとしたものである。本論文の概要は以下の3点にまとめられる。

- (1) 政策オン型の強化学習であるADPをマルチエージェントモデルに組み込み、顧客の需要変動を考慮して利害関係者が動的に意思決定を行うアダプティブマネジメントを取り扱うことができるモデルを構築した。利害関係者間の相互作用を評価できる方法論を開発した点に新規性が認められる。
- (2) このモデルを仮想道路ネットワークに適用し、ADPを用いた場合のほうが、従来のQ-学習を用いた場合よりも、物流コストの推定精度を向上させ、物流事業者のコストを削減し、共同配送センター管理者の利益を増大させ、またCO₂、NO_x、SPM排出量などの環境負荷も低減させることを明らかにした。このような結果は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大いに貢献することができる。
- (3) さらに、ここで開発したマルチエージェントモデルを横浜市の実際の道路ネットワークに適用し、ADPに基づく強化学習を適用することによって、Q-学習を用いた場合よりも需要変動に対応したアダプティブマネジメントをより効率的に行えることを示した。

このように複数の利害関係者が関係する都市内物流の共同配送システムについて、毎日変動する需要を考慮して、利害関係者の行動をシミュレートできるマルチエージェントモデルを構築したことは、複数の評価基準を満たすバランスのとれた都市物流施策を立案実行することに多大の貢献ができるものと考えられる。

本論文は、効率的かつ環境にやさしい都市内物流システムの構築のために、学術上、實際上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30年8月27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。

なお、本論文は、京都大学学位規程第14条第2項に該当するものと判断し、公表に際しては、当該論文の全文に代えてその内容を要約したものとすることを認める。