

京都大学	博士（工 学）	氏名	TEO SZE ERN, JOEL
論文題目	EVALUATION OF CITY LOGISTICS SCHEMES WITH MULTI-AGENT SYSTEMS LEARNING MODELS (マルチエージェント学習モデルを用いたシティロジスティクス施策の評価)		
(論文内容の要旨) This research provided new multi-agent systems (MAS) learning models aimed at incorporating multiple stakeholders’ objectives to evaluate city logistics schemes. The MAS models included the vehicle routing problem with soft time window model (VRPSTW) solved using insertion heuristics and a reinforcement learning model, Q-learning, to incorporate decision making and interaction of major stakeholders, including carriers, shippers, customers and administrators. Methods and results of the research have been summarized within 6 chapters. Chapter 1 introduced the motivation of research due to the aging society and especially with a computer literate aging population in developing or developed countries in the Asia-pacific region like Japan and Singapore. These factors, which are accompanied by the rising trend of online shopping is likely to increase the freight traffic, especially in home delivery. The potential impacts like environmental pollution from the increase in freight traffic will also raise the negative effect on the health of the city dwellers. Optimization models and simulation have been used in the past to evaluate city logistics measures and more recently the multi-agent systems (MAS) modeling approach has been experimented. The MAS approach is widely recognized as a way of modeling individual agent behavior and interaction while gradually expanding the model to cover all agents within a system. Such approach hopes to discover the evolving behavioral phenomenon among agents, which sometimes is impossible for other modeling approaches to accomplish when they evaluate city logistics schemes. Chapter 2 of this research provided the literature review beginning with the introduction of existing evaluation models for city logistics followed by the work of MAS models in general. MAS modeling has been applied on several traffic engineering and transportation problems for example in the area of urban traffic control and problems related to solving traffic congestion due to urbanization. MAS modeling approach has also gain popularity in the area of supply chain management due to the similar characteristics of supply chain management systems with multi-agent systems. In the field of supply chain management, each of the manufacturing company are considered to perform autonomously, interacts and communicates with other companies for orders and services, adapts to the changing environment by reacting to the perception of the evolving market and having the added initiative of launching innovative products. In city logistics, MAS modeling has been done to compare the vehicle routing problem with time window – dynamic (VRPTW-D) and vehicle routing problem with time window – forecasted (VRPTW-F) to evaluate city logistics measures like road pricing, subsidies to shippers and co-operative freight transport systems. Other researchers studied on the VRPTW-F model and compared the results with the Monte Carlo and Q-learning models to evaluate schemes like road pricing, truck ban and discounted toll fee. There is also a recent work of using MAS modeling approach to evaluate the dynamic usage of urban distribution center. Due to the multi-disciplinary nature of MAS approach, several models from cross disciplines are recommended including operation research, artificial intelligence, machine learning and game theory. Chapter 3 described the development of a new MAS learning model that included a second price auctioning model to represent the theoretical interaction between the shipper and carrier relationship in a freight marketplace. Second price auctioning was used initially due to its simple game theoretic mechanism, to determine carriers’ decision to price their service and shippers’ decision to choose the carriers. This MAS learning model was used to evaluate the urban freight distance-based and cordon-based road pricing schemes			

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implemented by the administrator using the Q-learning algorithm. The MAS learning model was tested on a hypothetical road network. It was observed that the cordon-based pricing scheme performed better than the distance-based pricing in reducing the nitrogen oxide (NOx) level in the city center and had almost a 45% reduction of the mean NOx level in the city center compared to the case when there was no pricing. However, the distance-based pricing, which performed less effective than the cordon-pricing in the city center showed better reduction in the NOx level when considering the entire city emissions. The profit margin of the carriers was found to increase when only the second price auctioning was used to represent the carrier and shipper interaction. The profit margin of the carriers rose further when the distance-based pricing was implemented. The distance-based road pricing was concluded to benefit the administrator's objective of keeping the NOx level lower, improving the carriers' distance travelled and profit margin, but was considered undesirable for the shippers in terms of the delivery cost. Chapter 4 included a new shipper-carrier Q-learning model in the MAS model to compare the results of the MAS model with second price auctioning. Although the second price auctioning model leads to shippers' objective of receiving a "true bid" by carriers and is a weakly dominant strategy to bid at ones' true value, such bidding may not have considered the level of service required by customers. In view of using the appropriate shipper-carrier model for evaluating other city logistics schemes, the shippers' decision to select carriers was experimented with the shippers' Q-learning model, which incorporated the complaints received by customers. The MAS learning model extended further to include the carriers' Q-learning model and their decision of price markup and discounting due to complaints received. It was found that the MAS model with shipper-carrier Q-learning model provided lesser environmental emissions and complaints of the customers due to delayed deliveries Chapter 5 advanced the findings from previous chapters to study on other schemes that can be applied along with urban freight road pricing as it was noted that road pricing alone may not be effective to provide a win-win situation that meets all the objectives of the stakeholders. The results of single scheme, distance-based road pricing, showed promising environmental benefits but had adverse effect to the shippers' cost. Following the discontinued load factor control trial scheme in Amsterdam and Copenhagen, a new load factor control (LFC) scheme considered in this research seeks to waive the distance-based road pricing charges to carriers if the trucks were able to obtain average load factor of more than 70% and higher. The results from the multi-agent learning model showed that load factor control scheme can be implemented together with the freight road pricing scheme with benefits to all agents considered. Although the LFC scheme caused the emission level to rise in the city center, it had several other benefits to all stakeholders. The cumulative distance traveled by the trucks reduced by about 5% and all the shippers enjoyed cost savings of up to 36% when the distance-based pricing was implemented together with the LFC scheme. The reduced delivery costs led to all carriers benefiting from the profit margin increase of up to 34%. The reduction of the rate of pricing in the city center when the LFC scheme was implemented with the distance-based road pricing reflected a better management of the distance-based road pricing scheme as it was considered as the administrator's intention of not using the road pricing as a revenue generating measure. Finally, chapter 6 provides the main contribution, the concluding remarks and the future research aspects of the study.			

(論文審査の結果の要旨)

本論文は、新しいマルチエージェントシステム(MAS)モデルを開発し、都市における貨物車交通のマネジメントを行うために、道路ネットワーク上において、シティロジスティクス施策を評価することを目標に研究した成果についてまとめたものであり、得られた主な成果は次のとおりである。

1. 荷主と物流事業者の相互連関を表すために第2価格オークションモデルを採用したMASモデルを開発し、このモデルをシティロジスティクス施策としてロードプライシングを実施した場合に適用した。その結果、行政がQ-学習によって学習を行い、環境改善のためにロードプライシングを実施した場合、コードン課金および距離課金の両方において、都心部におけるトラックのNO_x排出量は削減されることが分かった。また都市全体については、距離課金のほうがコードン課金よりもNO_x排出量の削減が大きいことを示した。
2. 次に荷主と物流事業者の相互連関について、第2価格オークションモデルではなく、Q-学習モデルを採用した新しいMASモデルを開発し、前記のMASモデルと比較を行った。その結果、Q-学習モデルを採用したMASモデルは、第2価格オークションモデルを採用したMASモデルに比べてトラックのNO_x排出量が少なく、また顧客からのトラックの到着遅延による苦情も少ないことを示した。
3. さらにQ-学習モデルを採用したMASモデルを、距離課金のロードプライシングとトラックの積載率規制の両施策を同時に実施した場合に適用した。その結果両施策を同時に実施することによってロードプライシングのみを実施した場合に比べて都市全体の環境が改善されることが明らかになった。
4. ここで開発したQ-学習モデルを採用したMASモデルは、都市における荷主と物流事業者の相互連関を表現し、行政によるシティロジスティクス施策に対する荷主・物流事業者の行動を表現することができる。このモデルを用いることによって、シティロジスティクス施策を実施した場合の荷主と物流事業者のコストの変化および都市における環境改善を定量的に把握することができることを示唆している。このことは、効率的かつ環境に優しい都市物流システムを構築する際に、利害関係者がwin-winの関係を保ちながら目標を達成できる可能性を示している。

上述のように本論文は、Q-学習モデルを採用した新しいMASモデルを開発し、複数の利害関係者が関連する場合にシティロジスティクス施策を評価する方法論を示している。また道路ネットワーク上において、ロードプライシングとトラックの積載率規制などのシティロジスティクス施策の評価を行っており、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24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。