Title	複数目的・複数主体からなる多段階在庫配置問題の意思決定における人と機械の協働プロセス
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Abstract

In recent years, the advancement of computer processing (hereafter referred to as "machines"), such as deep learning, other advanced algorithms, and increased processing power, make more attention to further sophistication in decision-making through collaboration between humans and machines that take advantage of the features of each. In the research field of knowledge science as well, knowledge creation through mutual complementation between humans and machines has become an important research topic in the digital age. Most of the recent decision-making research using machines has focused on automation and support for problems with a single entity or in which there is a hierarchical relationship among multi-entity, such as superiors and subordinates, and where prioritization among the objectives is possible. Decision-making support for multi-objective and multi-entity situations has been a challenging area for the future. In this study, we focus on multi-objective, multi-entity decision-making. Then, in a multi-echelon inventory problem, a specific example of such a problem, we propose and implement a new collaborative process between humans and machines to clarify the effects of machines and collaborative processes on human decision-making.

According to Simon (1960), decision-making can separate into three processes: information, design, and selection activities. Schorsch et al. (2017) suggest information activities such as information gathering and monitoring, which are highly reproducible from historical data, and design activities such as optimization calculations and simulations should be handled by machines, while the main parts of selection activity should be in charge by humans, such as consideration of future scenarios and knowledge creation, which are less reproducible from historical data, and also final verification and judgment. Referring to these previous studies, we proposed a practical collaborative process. In our process, information and design activities are performed by machines mainly. And selection activities are performed by humans and machines interactively, converting multiple objectives from objective functions to constraints step by step to make decisions on a multi-echelon inventory allocation problem. Then, we developed the machine functions for information, design, and selection activities in the proposed process, as well as confirmed the effectiveness of the proposed human-machine collaborative process.

Firstly, we confirmed by the game theory that the proposed process enables multiple entities to reach an agreement. Then, we applied the proposed process to practical situations, conducted unstructured interviews with users, and analyzed the results using the thematic analysis method to confirm that it is possible to rational decision-making effectively and rapidly by the proposed process.

Secondly, we developed a simulation-based optimization method for a multi-echelon inventory problem that can derive a highly optimal solution in a shorter computation time than the genetic algorithm (GA), which is considered the most common method. The constrained Bayesian optimization approach employed in this study outperforms both GA and penalty-based Bayesian optimization in terms of optimality and computational efficiency.

Thirdly, the maritime transportation arrival prediction is the input data for the inventory allocation calculation and significantly impacts the calculation optimality. So, we developed a method that predicts more accurately than the Dijkstra method and A* algorithm, which have been the mainstream machine approaches in the past. There are cases where vessels do not arrive at the destination port as planned due to changes in weather conditions along the route. On the other hand, previous studies failed to consider future weather conditions. So, we proposed an arrival prediction method that considers future weather conditions in two steps: (1) route calculation and (2) navigation speed calculation, using a Bayesian learning approach. The prediction accuracy was 90%, superior to 62% in the previous study.

Finally, we extracted the five points as follows that should be kept in mind when considering the collaborative process between humans and machines in decision-making and consensus-building support in multi-objective, multi-entity situations, based on the analysis with the game theory and with thematic analysis of the interview result from several perspectives such as negotiation studies, the knowledge creation through mutual complementation between humans and machines and the trust from human to machine. (1) A process in which each actor gains more by adopting a cooperative strategy than by betraying one. (2) A process in which machines play the role of mediator and lead to principle-based negotiation. (3) Finding and expanding the areas where the machine can be more precise and delegate more authority than humans and entrust them to the machine. (4) Machine evaluates and optimizes the combination of multiple people's knowledge. (5) In areas where machines are in charge, establish an introduction step and mechanism for people to trust machines.

As described above, in this study, we proposed a collaborative process between humans and machines for multi-objective, multi-entity decision-making, which had been a future challenge area, using the multi-echelon inventory problem as an example. Then we confirmed the effectiveness of the proposed process and demonstrated the key points for designing decision-making processes for other similar situations.

Keywords: Human-machine collaboration, Multi-objective and multi-entity decision-making, Multi-echelon inventory problem, Simulation-based optimization, Prediction of maritime transportation