Session 3: Robotic Systems

Chair: René de Koster

Mahsa Alirezaei (Rotterdam School of Management) - The impact of safety and productivity reminders on warehouse driver behavior: A VR experiment

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Balancing the often-competing goals of productivity and safety is an ongoing challenge in Operations Management in general, and in warehouses specifically. Employees are often pushed to work faster in order to meet increasingly tight delivery deadlines, while accident risks are omnipresent. Organizations emphasize safe and productive work. However, the combined impact of emphasis on speed, quality, and safety in warehousing remains unclear. This study employs controlled laboratory experiments involving a Virtual Reality (VR) simulator to examine the impact of audio reminders on the performance of warehouse vehicle drivers. The VR technology makes it possible to offer a realistic and fully immersive experience to the participants, while not exposing them to real safety risks. Drawing on concepts from productivity-safety tradeoffs, we operationalize the constant pressure on safe and productive performance faced by warehouse employees through three types of audio reminders emphasizing productivity, safety, and safety combined with productivity. Furthermore, it is likely that workers with different types of personalities will be affected differently by the audio reminders. We therefore also measure individual differences between drivers; in terms of Regulatory Focus. This experiment is designed in a 2*2 factorial design, in which the safety audio reminders are considered a within-subject manipulation, and the productivity audio reminders are considered a between-subject manipulation. The results show that exposing warehouse vehicle drivers to productivity audio reminders can decrease the completion time of tasks by 10% to 13% without a significant effect on their safety performance. We also found that warehouse vehicle drivers with a higher promotion focus are significantly more productive. In contrast, warehouse vehicle drivers with a higher prevention focus show lower productivity.To apply these findings, companies can apply some mechanisms to remind their employees about the importance of productive performance, and also can reassign employees with a higher promotion focus to vehicle driving tasks to increase their productivity.

Bhoomica Nataraja (Eindhoven University of Technology) - Integrated Decisions for Robot-based Order Picking/Fulfillment Systems

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Developing order fulfilment techniques that perfectly fit all requirements of a warehouse and its customers can be a daunting task. Recent advancements in robotics and automation have enabled warehouses to adopt new ways to stay competitive with on-time deliveries. The new fulfilment systems bring many advantages, together with many challenges. We introduce an autonomous robot-based compact storage and retrieval system that fulfils the orders from a multi-deep gravity flow rack. Uniquely, we consider a problem that integrates four main operational order picking decisions; order batching, order positioning, retrieval sequencing, and bin relocation. The first decision chooses the customer orders to be grouped. The second decision determines the placement positions of those grouped orders. The third and fourth determine a retrieval sequence of items with a bin relocation plan. We formalize the resulting integrated problem and present an exact mathematical model that minimizes the retrieval time. The integrated problem accounts for order due times, storage layout, and order characteristics to ensure applicability in practice. To solve real-sized problems, we propose heuristic solution procedures. Our numerical analyses show that the proposed heuristics can obtain near-optimal

solutions in short computation times. The best heuristic is applied to explore managerial aspects and tested in a real-world case study for which the attained results are more effective than the company's current policy. We further employ deep reinforcement learning methods to solve the integrated problem in a dynamic environment.

Frederik Schulte (Delft University of Technology) - Human Aspects and Performance in Collaborative Order Picking—What if Robots Learned When to Give Humans a Break?

Human-oriented collaboration between humans and robots is widely considered one of the greatest challenges in the final steps of the 4th Industrial Revolution and an anticipated central question of the 5th Industrial Revolution. Order-picking in robotic mobile fulfillment systems (RMFS) is one of the applications in which human-robot collaboration is already a pivotal element of today’s working reality. Various authors have recognized and addressed the issue as shown in a survey paper (Grosse et al., 2017), a conceptual framework for the integration of humans aspects in planning approaches of ordering picking (Grosse et al., 2015), or specific operational models (e.g., Merschformann et al. (2019)). Almost all of these works, however, assume a priori strain reactions of a human worker caused by certain work activity. That is, they do not consider real-time data to control the human strain reactions. This makes it difficult to consider individual characteristics of a human and their dynamic exhaustion and recovery behavior. Niu et al. (2021), on the other hand, propose a decision support approach that enables robots to learn a humanoriented assignment policy in collaborative order picking based on a discomfort model introduced by Larco et al. (2017). Recently, Sedighi-Maman et al. (2020) have demonstrated how sensor data from wearable devices can be used to detect the stress levels and recovery of workers. Niu & Schulte (2021), build on these findings in an integrated Multi-Agent Reinforcement Learning (MARL) approach that learns to take (assignment) decisions based on sensor data that is indicating human stress and recovery levels. While the authors demonstrate that the approach has significant advantages in terms of stress time and efficiency in comparison to multiple benchmark policies, the developed MARL approach has not yet been compared to the optimization approaches commonly applied for this type of problems. In RMFSs, most related works focus on different variants of operational assignment problems considering a general assignment between work stations and robots (Zou et al., 2017), shelves to storage assignment (Weidinger et al., 2018), order and storage assignment (Merschformann et al., 2019), velocity-based storage assignment (Yuan et al., 2019), and robots to shelves assignment (Roy et al., 2019). Apart from that, workstation location problems (Lamballais et al., 2017), pod travel times under different lane characteristics (Wang et al., 2020), fleet sizing (Zhou et al., 2016), path planning (Zou et al., 2017), and order batching and shelf sequencing (Boysen et al., 2017) are considered. The most common methods are statistical, analytical, and queuing models as well as optimization models. Only Zhou et al. (2016) propose a MARL negotiation scheme and apply it to an order picking example application, and Lamballais et al. (2017) develop a discrete-event simulation framework for RMFSs. Among these references, only Zou et al. (2017) consider human aspects using the proxy of the workers’ handling speed. In this work, we propose a multi-agent reinforcement learning (MARL) approach in which robotic agents effectively learn to consider human needs for recovery based on real-time data from wearable sensors, next to conventional objectives, such as minimum processing times. In this way, we avoid making strict a priori assumptions of the human stress reactions as often done in ergonomics and human-oriented order picking. The proposed policy considers short breaks for workers that are implemented via assignment decisions. For the conducted experimental study, we develop four different policies that are commonly deployed in order picking, and also compare the results to established optimization approaches proposed by Zou et al. (2017) and others. We find that the proposed MARL reduces the total stress time for humans by up to 45 % during the collaborative order picking process without significantly compromising the system efficiency. Since the general characteristics of the considered human-oriented assignment problem resemble many other operational problems including human-robot collaboration, the MARL approach may also be adopted in different and new problem settings in human-oriented operations research.

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