Two-echelon Multi-trip Vehicle Routing Problem with Synchronization for An Integrated Water- and Land-based Transportation System

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This study explores the benefits of an *integrated water- and land-based transportation* (IWLT) system for waste collection in the city of Amsterdam using autonomous vessels and *light electric freight vehicles* (LEFVs) in coordination and synchronization to reduce congestion-related externalities as well as the damage on fragile quay walls caused by heavy garbage trucks. The integrated system is modeled as a rich variant of the two-echelon vehicle routing problem considering: time windows at neighbourhoods; multi-trips for limited capacitated LEFVs; temporal and spatial synchronization of the vehicles involved in transfer operations; and capacitated hubs allowing a single transfer operation at a time due to limited space and manoeuvring capabilities of LEFVs. We propose a new mixed integer linear program (MILP) formulation of this problem that aims at optimally routing LEFVs and vessels as well as deciding the transfers and hub assignments to reduce overall logistics costs. A Logic-based Benders Decomposition (LBBD) method is proposed to solve the problem at land and water levels iteratively instead of solving the integrated problem at once. Computational experiments show that the LBBD outperforms MILP in terms of solution time and quality for even smaller instances up to 20 waste points. Furthermore, several heuristics are incorporated into the LBBD to find optimal solutions to medium-sized instances while they are also used to solve larger instances to provide insights into such IWLT systems with synchronized transfer operations. The proposed system with synchronized autonomous vessels and LEFVs is shown to be a promising solution for the issues with the current system by reducing the total travel time of the garbage vehicles on the street by 18% and the weighted average loads of the vehicles by 70% on average compared to different benchmarks. We believe that proposed methodology can be adapted to real case studies in Amsterdam to analyze the efficiency, reliability and sustainability of such an IWLT system considering deterministic settings as well as stochastic cases.

Acknowledgement
This research is supported by the project "Sustainable Transportation and Logistics over Water: Electrification, Automation and Optimization (TRiLOGy)" of the Netherlands Organization for Scientific Research (NWO), domain Science (ENW), and by the Researchlab Autonomous Shipping at TUDelft.